SCIENCE&ENGINEERING SYMPOSIUM

PROCEEDINGS

16-19 OCTOBER

SCIENCE & ENGINEERING SYMPOSIUM 1978 SAN DIEGO CALIFORNIA

THEME: "Advanced Technologies – Key to Capabilities at Affordable Costs"

VOL. VII. HUMAN RESOURCES

CO-SPONSORED BY
NAVAL MATERIAL COMMAND
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DEPARTMENT OF THE NAVY NAVAL MATERIAL COMMAND

- Avionics
- Propulsion
- Flight Dynamics
- Basic Research
- Material
- Armament
- Human Resources

PROCEEDINGS

OF THE

1978 SCIENCE AND ENGINEERING SYMPOSIUM

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NAVAL AMPHIBIOUS BASE
CORONADO, CALIFORNIA

VOLUME VII

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PREFACE

The initial co-sponsored Air Force Systems Command/Naval Material Command Science and Engineering Symposium was held at the Naval Amphibious Base, Coronado on 16 - 19 October 1978. The theme of the 1978 Symposium was "Advanced Technologies - Key to Capabilities at Affordable Cost."

The objectives of this first joint Navy/Air Force Science and Engineering Symposium were to:

- Provide a forum for military and civilian laboratory scientific and technical researchers to demonstrate the spectrum and nature of 1978 achievements by their services in the areas of
  - Armament
  - Avionics
  - Basic Research
  - Flight Dynamics
  - Human Resources
  - Materials
  - Propulsion
- Recognize outstanding technical achievement in each of these areas and select the outstanding technical paper within the Navy and the Air Force for 1978
- Assist in placing the future Air Research and Development of both services in correct perspective and to promote the exchange of ideas between the Navy and Air Force Laboratories
- Stress the need for imagination, vision and overall excellence within the technology community, assuring that the air systems of the future will not only be effective but affordable.

Based upon the success of the initial joint symposium (which was heretofore an Air Force event), future symposia are planned with joint Navy/Air Force participation.

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MATERIALS, ARMAMENT, AND HUMAN RESOURCES
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HUMAN RESOURCES RESEARCH AND DEVELOPMENT

BY

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Introduction

During tomorrow's session on Human Resources, you will hear six Air Force papers; four from the Air Force Human Resources Laboratory (AFHRL) and two from the Aerospace Medical Division (AMD). Both organizations are more people oriented than hardware oriented, and both contribute to Air Force readiness through the development of new technologies and devices designed to increase man's productivity and safety. My purpose today is to provide you with a broad overview of the R&D programs of each of these organizations.

AF Human Resources Laboratory

The Human Resources Laboratory (HRL) was established in 1968 and, since that time, has had an R&D mission in the areas of personnel utilization, flying training technology, and technical training technology. For the past few years, the emphasis has been on flying training technology, especially the design and utilization of advanced flight simulators.

The Laboratory has six divisions; three are colocated with the HQ at Brooks AFB, Texas. These three are the Personnel Research Division, the Occupation and Manpower Research Division, and the Computational Sciences Division. All conduct R&D primarily in the area of personnel utilization.

Flying training and technical training R&D is conducted principally at the Flying Training and Technical Training Divisions at Williams AFB, Arizona and Lowry AFB, Colorado. The Advanced Systems Division at Wright-Patterson AFB, Ohio also contributes new technologies to the areas of flying training and technical training through the development of advanced simulator designs, techniques for improving the performance of maintenance technicians, and methods for predicting the human resources requirements of new weapon systems.

All AFHRL R&D is supported with 6.1, 6.2, and 6.3 funds. The personnel authorization is 367 positions requiring the talents of psychologists, engineers, computer scientists, econometricians, and educational technicians. Two hundred and thirty-three employees have degrees, 56 of them PhDs.

Personnel Utilization. The primary R&D objective in the area of personnel utilization is to optimally match the person to the job. This task is particularly challenging

at the present time because the Air Force is faced with a declining manpower pool, high rates of attrition, and an increased need for superior job performance to support increasingly complex weapon systems. Since Air Force jobs require a variety of personnel talents, differential selection techniques based on a full understanding of job and task requirements are required. Thus, the AFHRL R&D program in personnel utilization focuses on developing improved techniques for personnel selection and job assignment. Studies conducted include development and test of new selection devices; specification of job aptitude requirements; assessment of job performance and job satisfaction; and development of models of the Air Force manpower and personnel system. These requirements are fulfilled at the request of the Deputy Chief of Staff for Personnel, other Air Staff offices, and the major air commands (MAJCOMs), through a formal request procedure specified in AFR 80-51. Approximately 50% of all AFHRL R&D is conducted in response to such formal requests while the remainder is conducted in response to technology needs, regulations, letter requests, and work unit proposals submitted by AFHRL scientists.

Recent products in the area of personnel utilization include: (1) a person-job match algorithm which matches enlistee talents with available Air Force jobs; (2) UPT selection procedures which could reduce selection costs; (3) specification of minimum aptitude requirements for Air Force jobs; and (4) development of a Vocational Interest Inventory (VOICE) which when used with other selection instruments will increase the probability of enlisted job satisfaction and retention.

Technical Training Technology. The Laboratory thrust in technical training technology has focused on developing advanced instructional technologies for use in technical training courses. The technologies developed are computer based and managed, self-paced, multi-media, and learner centered. They were developed for initial use at the ATC Lowry Technical Training Center and have been implemented in four Lowry technical training courses with an associated cost savings of over $6 million dollars.

While R&D on computer based instructional technology continues at the Technical Training Division, a new emphasis is being placed on maintenance simulation techniques. A first step has been the acquisition and evaluation of a maintenance training simulator which can be used in place of the actual flight control and avionics test station for

the F-111 aircraft. Advantages of using maintenance simulators in technical training parallel benefits already gained using flight simulators. They include reduced cost of acquisition, reduced life cycle costs, and improved training capability, such as the capability to insert faults into the simulator for student isolation. These training exercises can be conducted without exposing the student to the dangerous voltages which exist in the actual equipment.

Flying Training Technology. The current emphasis in flying training technology is to improve the utilization of simulators. AFHRL also develops simulator design improvements when theproposed design is expected to result in an improved training capability. Current design efforts will improve: (a) visual displays and G-cueing techniques for air-to-air and air-to-ground simulation, and (b) sensor (LLLTV, IR) simulation displays for aircrew training.

The evaluation of new simulator design concepts is conducted using the Advanced Simulator for Pilot Training (ASPT) located at the AFHRL Flying Training Division at Williams AFB. When first installed in 1975, the ASPT consisted of two T-37 cockpits, a 6° of freedom motion platform, and a wraparound computer image generated display. Considerable R&D has been completed in support of Air Training Command (ATC) and, more recently, in support of Tactical Air Command (TAC). Major projects completed for ATC include development of a syllabus for the ATC Instrument Flight Simulator and specification of simulator motion requirements for undergraduate pilot training. Current projects in support of TAC are A-10 and F-16 transition training/research programs for which the ASPT has been modified, and development of a skills maintenance program for TAC pilots. Studies in air-to-air combat techniques are also being supported by AFHRL at Luke AFB using the simulator for air-to-air combat.

Major FY79 thrusts in flying training R&D are the design and development of an improved air-to-air/air-to-ground tactical air combat display, development of automated performance measures for aircraft and simulators, design and evaluation of low-cost G-cueing devices, and specification of methods for measuring and maintaining aircrew skills.

For the Laboratory in general, the major thrusts for FY79 and 80 are: computer based selection testing, aptitude requirements for AF jobs, maintenance of piloting skills, design specifications for maintenance simulators, specifications for advanced air combat displays, and improved force and motion cueing techniques.

Aerospace Medical Division*

The Aerospace Medical Division has important mission responsibilities in medical education and medical care; however, today I will discuss only the AMD R&D mission. That mission is accomplished by the School of Aerospace Medicine (SAM) and the Aerospace Medical Research Laboratory (AMRL) under the direction of the AMD Directorate of Research and Development located at HQ AMD, Brooks AFB, Texas.

The AMD R&D mission, referred to as Aerospace Biotechnology, is to conduct RDT&E in support of crew-centered design of weapon systems and in support of the operation of manned Air Force weapon systems. To accomplish that mission, AMD is authorized 995 R&D personnel and has several unique research facilities. These facilities include biodynamic simulators, toxic chemical exposure chambers, electromagnetic radiation sources, and systems for evaluating man-in-the-loop.

Aerospace biotechnology is organized into seven Technology Planning Objectives. Each of the seven R&D divisions of SAM and AMRL is responsible for a specific Technology Planning Objective and its supporting project. Major objectives address the following technical areas: 1) Environmental Toxicology, 2) Radiation Hazards, 3) Mechanical Forces, 4) Man-Machine Integration, 5) Aerospace Medicine, 6) Crew Technology, and 7) Manned Weapon Systems Effectiveness.

Biotechnology products include human criteria for system development and acquisition, and human standards for crew safety and environmental quality. The user incorporates these products into design analyses, concept demonstrations, and operational planning. The return to the Air Force is

*Significant contributions were made to this section by personnel of AMD/RD.

improved readiness, a reduction in life cycle costs, and human benefits. Biotechnology products have a wide range of customers: the AFSC product divisions and hardware laboratories, the Air Force Surgeon General, and the major air commands.

There are three major thrusts in the Biotechnology area: (a) Manned Weapons Effectiveness, (b) Capability Enhancement, and (c) Safety and Environmental Quality. I will describe the objectives of each.

Manned Weapons Effectiveness. The objectives of the Manned Weapons Effectiveness research program are principally directed toward assessment of blue (friendly) system vs red (threat) system capability and the development of human countermeasures. Blue system technology is focused on 1) developing a fundamental understanding of man's perceptual/motor and cognitive performance; 2) translating fundamental information on human behavior into design standards and criteria; 3) developing from this human performance data base specific hardware and software products that enhance man's ability to conduct air operations; 4) accomplishing design simulations of man-machine systems to provide specific software and hardware solutions for strategic, tactical, and command and control weapon systems; and 5) providing direct consultative support to weapon systems undergoing development by the various divisions of the Air Force Systems Command.

Red system technology concentrates on: 1) the quantification of human operator contributions to foreign threat weapon system effectiveness, and 2) the development of techniques to reduce or nullify the effectiveness of threat weapon systems operators. It is generally accepted that a valid description of the crew subsystem is the crux of viable weapon system effectiveness evaluation. Sensitivity evaluations of large-scale engagements using analytical techniques are conducted to determine crew impact on the total system and the level of confidence which may be placed on system effectiveness predictions. Increasing requirements for analysis of Air Force weapon system capability and survivability conflict with the high costs of flight and field tests. This situation underscores the need to describe crew subsystems in the same terms as other weapon system components so that automated analyses can be accomplished at much lower cost.

Capability Enhancement. The Capability Enhancement thrust encompasses crew protection, crew readiness, and fitness to fly. Diminishing availability, increased cost, and more demanding mission requirements dictate the need to employ air and ground crews with maximum efficiency. The requirement for weapon systems to operate in an environment of expanding threats to man's capability has underscored the need for advanced life support equipment to replace currently available life support assemblies that are increasingly costly. Thus, in the area of crew protection, AMD is developing design criteria for protective equipment for the aircrew, and environmental control and emergency escape systems for the aircraft. Crew readiness research focuses on establishing criteria for crew ratio requirements, duty schedules, and sortie surge which may be encountered in rapid overseas deployment. Possible aircrew fatigue is the central concern in establishing these criteria. In the fitness to fly area, AMD has the mission of establishing criteria for medical selection and retention of UPT and UNT applicants. Qualified pilots are also evaluated when medical problems arise. AMD is also involved in developing patient monitoring equipment for air evacuation aircraft.

Safety and Environmental Quality. The objectives of the Safety and Environmental Quality research program center around the prediction, assessment, and specification of safe exposure limits for airbase noise, electromagnetic radiation and military chemicals. Noise research is providing criteria for compatible land use in the vicinity of the airbase as well as safety standards to protect air and ground crew personnel in Air Force noise environments. The objectives of the radiation bioeffects research program are to assess hazards, quantify acute and delayed biologic effects of nonionizing laser/maser, nuclear flash, radiofrequency, and ionizing radiation on man. The objectives of the toxicology research programs are to protect, maintain, and enhance the performance of Air Force personnel in potentially hazardous chemical environments associated with the operation and maintenance of aircraft and missile weapons systems. The exposure hazard covers the entire spectrum of low-level continuous or intermittent to high-level brief accidental or unavoidable exposures. Bioeffects data are required to establish standards compatible with recent Federal legislation concerning occupational safety and health, and control of hazardous materials in the context of both military operations and environmental quality.

In summary, the major R&D thrusts of AFHRL are Personnel Utilization, Technical Training Technology and Flying Training Technology. The major R&D thrusts of AMD are Manned Weapons Effectiveness, Capability Enhancement, and Safety and Environmental Quality. Both organizations contribute significantly to the effectiveness and readiness of Air Force operations through the development of new technologies and devices designed to increase man's productivity and safety.

Biographical Sketch

Dr. Herbert J. Clark is Chief, Plans and Programs, Headquarters Air Force Human Resources Laboratory, Brooks Air Force Base, Texas. He is responsible for directing and administering the plans and programs of six Laboratory divisions and serves as the principal research and development director of the Laboratory. He holds MA and Ph.D degrees from the University of Illinois and an AB from the University of Michigan. He is also a 1975 resident graduate of the Industrial College of the Armed Forces. Dr. Clark has been employed as a civilian with the Department of the Air Force since 1964, and has taught graduate and undergraduate courses at the University of Illinois, University of Dayton, and Wright State University. His publications are in the areas of human perception, human performance, spacecraft simulation, and organizational development. He has directed research and development in areas of human engineering, technical training, flying training, and personnel selection and classification. He is a member of Sigma Xi and several professional organizations.

HUMAN RESOURCES

IN NAVAL AVIATION

Functional Area Review

- 1978 -

By

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Naval Training Equipment Center
Orlando, Florida

Human Resources in Naval Aviation

Abstract

The objectives of the Navy Training and Personnel Technology Program are to achieve best use of military manpower and to make a significant contribution to the readiness of operational forces. Problems dealt with in this program include personnel acquisition, training, manpower management, and the human/weapons system performance interface.

A matter of concern for the Training and Personnel Technology Program, as for all Navy programs, is that of cost. Manpower and related costs for the Department of Defense represent the largest single expense, amounting to almost 60 percent of the total defense budget. Effective and economical use of these manpower resources is a matter of top priority. At the same time, it is necessary to control costs for military hardware. A single aircraft can cost well over $20 million. Full benefit from our investment in both manpower and hardware can only be realized, however, if proper attention is given to the personnel factors in Navy systems, including training, utilization, and maintenance. This paper reviews use of human resources in the Navy, discusses some cost factors, and describes significant trends and representative RDT&E efforts. Particular note is taken of advanced technologies being used and their potential for improving cost-benefit ratios for new Navy weapon systems.

Introduction

The advanced technologies now being applied to the design of weapons systems are resulting in dramatic increases in military capabilities and effectiveness. However, with each technological stride there is a cost, often little-noted or anticipated, in the roles, tasks, and commitments of personnel. Someone must decide how the new system will be used; someone must learn to operate it; someone must maintain it. However simply stated here, these issues are not easily resolved in the real world. The application of new technologies often results in systems which, although impressive from the strict military view, are exceedingly difficult to understand, to operate, and to maintain. The resulting mismatch between the hardware and personnel components of new systems can add considerably to system costs while at the same time reducing effectiveness. One important way of improving the cost/effectiveness ratio for new systems is through advances in the technology with which we use our human resources.

The theme of this conference concerns applications of new technologies in military systems at affordable costs. Proper resolution of "operator" issues can do much to lower total system costs. However, this is a two-edged issue. While striving to lower system costs, one must not let the personnel technology itself become too expensive. This paper reviews use of human resources in the Navy, discusses some cost factors, and describes significant trends and representative RDT&E efforts.

The term "Human Resources" is global and has varying and sometimes misleading definitions. For example, the Navy now has a Human Resources Management Program which concentrates on maximizing the effectiveness of Navy men and women by dealing with issues of drug abuse, alcohol abuse, and equal opportunity. To reduce the confusion in terminology, Congress agreed with DoD's desire to adopt the term "Training and Personnel Technology Programs" to cover topics of concern in this report. In the House Armed Services Committee report accompanying the FY 1979 DoD Authorization Bill, it was recommended that future budget elements of this program be divided into four categories as shown in Exhibit 1. Specific program tasks were defined by the Committee as follows:

Training Devices and Simulators - All efforts to design and develop maintenance, flight, and combat engagement simulators.

Human Factors - All efforts to develop techniques, procedures, and criteria for the design of weapon systems so that they can be efficiently operated and maintained by military personnel.

Manpower and Personnel - All efforts to develop a better understanding of manpower requirements, methods of recruiting, incentives for retention, personnel management and organizational effectiveness.

Computer-Aided and Classroom Training[1] - All efforts to develop or adapt new techniques for training personnel. Examples include computer-managed training, lesson development, and handbook preparation.

Program Support and Facilities

The funding for the major areas in the Training and Personnel Technology Program, for all of DoD, is shown in Exhibit 2. The figures presented in the final column, for FY 1978, are an earlier estimate, with the actual funding now known to be around $90 million rather than the $104 million shown. Even so, the figures show a relative balance among the four areas as well as a modest growth over the three-year period.

Each technology area shown in Exhibit 1 supports a particular aspect of military operations. For example, "Human Factors" concerns the design of weapon systems for efficient utilization by human operators. Likewise, "Training Devices and Simulation" supports the development and utilization of training systems which serve both to improve the quality of training and to reduce the need to use operational systems as trainers.

In using a training device such as a flight simulator, there are two costs to consider. The first obviously is the cost of acquiring the device. This cost is not small.

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[1] DoD has substituted the term "Education and Training" to designate tasks in this category.

Over the past five years, the Department of Defense has invested about $1.3 billion in the development, acquisition, and modernization of flight simulators. In at least one instance, the cost of a single flight simulator has approached $25 million.

The second cost is that of developing a technology for efficient use of the simulator. Here there are many issues such as acceptance, fidelity, scheduling, measurement, and others. Suffice it to say that it is most important to see that our $1.3 billion investment produces the proper return in terms of lower flight-hour costs and increased combat readiness.

It is of interest now to compare the costs for the acquisition of flight simulators with the funding for the training and personnel technology area designed to support efficient use of these devices. Exhibit 3 shows the funding for procurement of Navy and Marine Corps flight simulators from FY 1976 through FY 1980. This is compared with funding for the training technology program which defines effective design and utilization of these simulators. This table shows that simulator acquisition costs rose rather dramatically until 1978, at which point they have stabilized at around $125 million per year. On the other hand, funding for the R&D technology to support use of these simulators, while showing a modest growth, has in fact decreased in relation to simulator costs. In 1976, supporting technology costs were about four percent of acquisition costs. At present, and for the next two years, the R&D funding has dropped to two percent. This relationship is presented graphically in Exhibit 4.

The relative decline in R&D funding for simulator support can be seen through another comparison. Exhibit 5 shows the total funds for all Navy efforts in the category of "Exploratory Development." This is compared with the total Navy and Marine Corps budget for the years 1976 through 1979. The Exploratory Development funds run at a constant one percent of the total Navy budget through this period. Thus, whereas the overall research funding is a fixed ratio to total Navy costs, that part which supports efficient use of simulators shows a decreasing ratio when compared with simulator acquisition costs.

The funding relationships just described have considerable implications for our R&D program. First, bearing in mind that there is a 1974 DoD mandate to reduce military

flying hours by 25 percent by 1981, there is an ever-growing need to develop optimized techniques for using simulators. The increasing supply of these training devices must be used to best advantage as a substitute for flight time and in such a manner as to improve combat readiness. Second, managers of the R&D technology effort are forced to work within a budget which has not shown the same growth as that noted for simulators themselves. This review will describe some of the ways in which we are meeting the challenge of providing proper personnel support while at the same time seeing that our technology development costs remain at an affordable level.

Exhibit 6 shows the principal Navy organizations engaged in RDT&E efforts dealing with the four Training and Personnel Technology elements. Depending upon the particular problem, any one of these facilities can work in direct support of a NAVAIR project manager.

Now that we have defined the scope of human resources, discussed cost constraints, and shown where the RDT&E program is conducted, we will describe issues, trends, and current efforts in this field.

Key Issues

There are a number of key issues, shown in Exhibit 7, which human resources programs must face. The first of these is the increasing number of new weapons, command and control, and surveillance systems now being introduced into the Fleet and the complexity of these systems. The numbers alone are most impressive. In the recently-completed Project HARDMAN report, dealing with military manpower versus hardware procurement, it was noted that there are presently in procurement some 700 different Navy projects involving approximately $90 billion.

A good example of the complexity of these new systems can be found in V/STOL aircraft technology. In a review of the human factors problems presented by these aircraft conducted by the Naval Air Systems Command, it was concluded that:

> *Demands in V/STOL of necessity place a higher priority upon stability, control and display relationships than do requirements for conventional flight. Current military specifications and*

standards are geared to the latter requirements, and fall far short of meeting the unique V/STOL challenge. Advanced technology programs . . . may afford the required hardware and software capabilities to satisfy many of the unique V/STOL requirements, but considerable effort will be required to define and refine the information, control and display concepts and requirements for implementation.

Another example of complexity issues can be found in the panel layout of new aircraft. The F-4 fighter had 1,750 square inches of space available for cockpit display. In the F-18, this has been reduced to 850 square inches, or approximately one-half. At the same time, the introduction of new target acquisition systems, such as FLIR, has considerably increased the information which must be displayed. This obviously means more information per display system and multipurpose displays. The additional information, combined with sequential presentation modes, can greatly increase aircrew workload and result in poorer rather than in better overall system performance.

A second issue of importance is that of system maintenance. Admiral Michaelis recently observed that the contribution of maintenance logistics to carrier operational and support costs is disproportionately high. With new aircraft such as the F-18, considerable attention is being given to increased reliability through improved engineering for maintainability and through new concepts to survey and control maintenance activities. For one, there will be a computer-based management information network during design and development, and continuing through Fleet introduction, to track all system failures. Admiral Michaelis predicts that increased reliability, along with improved maintainability, may reduce the requirement for maintenance personnel by as much as 20 percent over that for the F-4 aircraft. However, until such maintenance improvement is actually experienced, improvements in the training and support of maintenance personnel will be a top priority item.

A strong emphasis in maintenance training now is toward simulation. Maintenance simulators have more flexibility in use, expedite the training process, and most important, are considerably less expensive than actual equipment procured, as is often the case, solely for maintenance training purposes. The development and production

of maintenance simulators is a new market, one which we anticipate will grow quite rapidly in the next several years.

Complicating the problem of providing proper personnel support for new military systems is the fact that the basic supply of personnel is changing. Part of this simply is a drop in the supply. In FY 1977, the Navy did not meet its recruiting goal of slightly over 116,000 recruits, falling short by almost 4,800, while achieving a recruiting rate for high school diploma graduates of 3.4 percent age points less than desired.

In pilot training, the number of candidates entering training is adequate but retention after the first tour is deteriorating. From FY 1978 to FY 1979 a drop in retention from 49 percent to 39 percent is projected. Since a certain number of these pilots will leave the service no matter what incentive programs are introduced, it is up to us to see that these pilots achieve maximum operational capability while they are in service.

Another issue to be addressed is the relationship between the human resources R&D community and the Fleet. Although in concept all R&D activities in some manner should ultimately support Fleet readiness, the proper balance to be achieved among short-, mid-, and long-term payoffs has not always been clear to either researcher or user. Recently, however, there has been a concerted effort to improve awareness of this situation for both sides. For example, in June 1977, the Navy sponsored a three and one-half day symposium dealing with the utilization of people-related research. Key DoD decision makers, technical advisory groups, and potential users of military research were present at this symposium. Other efforts such as this are planned in an ongoing program to improve the exchange of requirements information on one hand and research findings on the other.

The final issue is that of developing ways in which the pay-off from "human resources" RDT&E activities can be clearly demonstrated. There is a need to evaluate these research efforts in objective measures describing improved system performance and/or decreased costs for system development and operation. Evaluations such as this are needed on two counts. First, we must be able to demonstrate, particularly to those responsible for budget allocations,

that the human resources technology, easily justified rationally, can be just as easily justified in terms of objective value to the Navy. Second, evaluation data are important to research managers as a basis for continuing improvements in our human resources technologies.

Trends

Within the past five years, there have been a number of significant changes and reorganizations within the Navy human resources community. Principally, there is more cohesion in the effort today so that the overall power of the program can be brought to bear on specific Navy problems. For example, in support of the F-18 aircraft program, there are a number of separate R&D efforts underway at different facilities. However, these are not independent activities conducted along specific lines of interest to the principal investigator, as might have been the case in earlier days. They now are part of a coordinated effort in which Fleet requirements are processed through the Naval Air Systems Command and its lead laboratory, the Naval Air Development Center. The activities of the different laboratories thus are focused toward the single objective of providing greatly improved personnel support for the F-18.

Exhibit 8 shows some specific trends now underway in human resources RDT&E activities. The first of these is the incorporation of advanced technologies into human resources programs, just as these technologies underlie the development of actual weapon systems. For instance, a new program at the Naval Training Equipment Center is incorporating the use of minicomputer and microprocessor technology into the development of low-cost, part-task training devices which may be acquired in quantity. Such devices should improve the quality of pilot training as well as reduce the requirement for very expensive full-mission simulators. In this program, the pilot trainee sits in front of a small console containing a minicomputer graphics display. Instruments are shown in the lower half of the display with an out-of-the-window view in the top half. There are appropriate controls for stick, throttle, radio, and weapons control. The minicomputer performs all simulation computations, as well as handling scoring and problem set-up. Catalogs of various aircraft dynamics and exercises are available on floppy discs. Sample problems include night carrier landing, approach and landing at a bingo field, and real-time gun-sight operations.

Interchangeable control modules allow representation of various Naval Flight Officer functions, such as those of the Radar Intercept Officer. The first of these devices is scheduled for evaluation at a Fleet squadron in FY 1979 to assess the impact of this kind of training on night landing performance as measured during pre-deployment training.

The second trend involves a much greater use of computers and computer-modeling. The Naval Air Development Center has had a vigorous program underway in this respect. They have developed the Computer-Aided Function Allocation and Evaluation System, with a number of subprograms which greatly improve our capability to deal with operator issues during aircraft design, development, and evaluation. These models include one called the Human Operator Simulator. Through use of this model, and other subroutines, it is possible to deal with problems of function allocation, workload assessment, internal design, and control/display groupings. The model for operator simulation currently is being adapted for cost-effectiveness estimation. Through simulation of the complete hardware/software/operator system, it will provide predictions of effectiveness attributable to proposed avionics changes and will allow us to determine, prior to implementation of these changes, which of several configurations produces the greatest increase in total system performance, with the role of the human operator fully taken into account in each configuration.

A third trend concerns the movement toward greater exchange of data within human resources disciplines. This serves to make the entire human resources effort more cost-effective and makes outputs more timely. For example, computer models for different human engineering tasks produce data files which have immediate utility for training. In the case of function allocation and workload prediction models, data can either be used directly for training analyses or can serve as the beginning point for necessary design modifications. This being the case, we hope to develop means which will allow automatic hand-off of common data between such facilities as the Naval Air Development Center and the Naval Training Equipment Center. A computerized link would mean that, as some change is made in system design, we could rapidly assess its implications for change in training system planning. It also means that the Navy would pay only once for the development of a data base. This is not always the case now.

The final trend of importance is the increased involvement of the Fleet in the development of training systems. The interaction and cooperation between Fleet personnel and training personnel is considerable and occurs at all stages in the development of training hardware. The LAMPS system provides a good example of how this cooperation works, as shown in Exhibit 9. At the present time, a training committee has been established to review requirements and to develop guidelines for production and use of training equipment. This training committee includes representatives from the Chief of Naval Operations, the Naval Air Systems Command, the Chief of Naval Education and Training, Atlantic and Pacific Fleet Commands, and a number of the Navy laboratories, with the Naval Training Equipment Center serving as Program Manager. There also is a Fleet training team located at the site of the weapon system prime contractor to coordinate and review the acquisition of training hardware. Subsequently, as the weapon system becomes operational, there will be a Fleet project team to review the design of simulation equipment and a Fleet implementation team to aid the integration of simulation equipment into the training schedule and to develop evaluation programs.

Current Activities

A brief review of ongoing projects will show the kind of effort now underway in each of the four categories described earlier in Exhibit 1. These projects also provide examples of the way human resources efforts are helping the Navy achieve the "affordability" goal.

Training Devices and Simulators

Due both to the needs for cost reduction and energy conservation, there is considerable interest in the development of new and improved simulation equipment. In fact, Congress has mandated that the services will use simulators in support of flight training to the fullest extent possible. An obvious impetus is the dramatic reduction in costs which can be achieved, as shown in Exhibit 10. The data on which these summary figures are based come from Air Force, Army, Navy, and commercial sources. Since many assumptions were made in the use of this information, the costs shown represent an estimate only, although one would expect that this estimate is quite close. In any event, it is reasonable to anticipate a ten-to-one reduction in costs when efficient simulators are used to replace aircraft flight hours.

A major effort now underway at the Naval Training Equipment Center concerns the development of an advanced R&D facility, known as the Aviation Wide Angle Visual System (AWAVS), shown in Exhibit 11. Use of this facility will allow us to examine the most affordable and flexible ways of presenting visual information to aircrewmen in simulators. In AWAVS, there are two independent television projectors and a wide angle display screen. The wide angle projector displays the background scene while the narrow angle target projector provides high resolution target images. Projectors are fed from a flexible-image storage system which includes three-dimensional models, two-dimensional film and computer image-generation equipment. Upon completion, the AWAVS system will represent a greater advance in display technology than any other simulator currently available. It will provide features of motion, configuration change flexibility, multiple image generation, visual streaming or ground growth cues, plus other capabilities. Ultimately this program will be capable of portraying missions for such advanced systems as V/STOL aircraft.

Human Factors

Most air-to-ground weapons currently in use require that the aircrew make a visual acquisition of the target before the weapon can be employed. However, in the evaluation of different weapons, such as bombs, guns, rockets, and guided missiles, effectiveness generally is based on delivery accuracy and target destruction. The probability of finding the target in time to attach and launch the weapon usually is ignored.

The Naval Weapons Center has developed a method for computing the probability of locating a ground target visually and then launching a weapon against it. Major factors used in the computations are target acquisition performance, aircraft maneuvering requirements, terrain masking, visibility, and weapon operating time. Estimates of these factors are based on real-world data whenever possible, as opposed to mathematical modeling. Exhibit 12 shows the kind of acquisition scene which can be dealt with by this method, in this case anti-tank missile launchers sited beside a road.

The results of the NWC study show that the probability of releasing or launching a weapon on a target is quite low in many situations. The method itself can be incorporated

as one part of the evaluation of a new air-to-ground weapon. It also can be used to provide an indication of the relative effectiveness of visual search versus electronic search.

Manpower and Personnel

The development of new weapon systems, and their subsequent manning, requires the forecasting with some precision of future personnel levels and requisite skills. Exhibit 13 shows that after 1980 the personnel supply will be in gradual reduction for some time. Under these conditions, the acquisition and appropriate use of personnel becomes of even greater importance than it is today.

The Navy Personnel Research and Development Center has several studies and modeling efforts underway to investigate the long range supply and appropriate utilization of manpower. Results of these studies will be important for the design and staffing of new weapons and support systems, particularly those which are manpower intensive. In addition, these studies define qualitative standards for personnel in terms of weapon system demands.

The Naval Aerospace Medical Research Laboratory, working with the Naval Training Equipment Center, is attempting to improve the selection process through use of synthetic task devices in selection. These devices, which in a limited way represent the operational world, should tap basic capacities not measured with more conventional tests. The result should be the selection of individuals more likely to succeed at the job under consideration. This will improve the Navy manpower situation and may also result in better retention rates.

Computer-Aided and Classroom Training

A continuing Navy concern is for procedures which will lead to improved aircrew survivability, particularly if the improvements can be achieved at an affordable cost. The Naval Air Systems Command recently undertook a study of special presentation formats in an aircraft NATOPS Manual as one way of possibly reducing the fatalities and injuries incurred during ejection from a disabled aircraft. This project also received support from the Navy Technical

Presentation Program (NTIPP) at the Navy Ship Research and Development Center because of its interest in the effects of technical manual format on the performance of time-critical, hazardous procedures.

An experiment was conducted during which the T-2 NATOPS ejection procedure presentations were redesigned employing state-of-the-art methods. Two groups of student naval aviators, each of which had completed ejection training, were selected. One group studied the standard NATOPS Manual. The other studied the revised presentation. Both groups were tested, as shown in Exhibit 14. These results indicate that the new write-up significantly increased the user's awareness of ejection seat limitations and of procedures needed to operate the hardware. If this knowledge is in turn reflected in better use of the seat and better understanding of the ejection envelope, as should be the case, this represents a low cost increase in aviation safety.

There is another effort underway which offers considerable training benefit as well as cost savings. For several years, an advanced simulator, the Night Carrier Landing Trainer, has been used by the Replacement Pilot Training Squadron, NAS Cecil Field, Florida. This is a sophisticated training simulator incorporating motion characteristics and all of the visual information available for a night carrier landing.

In a recently-completed study, the training effectiveness of the Night Carrier Landing Trainer, both for day and night landings, was evaluated. Exhibit 15 shows that for day landings, the performance of new aviators who were given NCLT training using remedial techniques based on an examination of errors during the training cycle was superior to all groups, including A-7 pilots with combat experience. For night landings, again the novice aviators with remedial NCLT training were above average. The most direct evaluation, however, comes from the considerable improvement in night landing performance of new aviators with NCLT training, but with no special remedial aspects, over that of new aviators who did not use the Night Carrier Landing Trainer. The training benefit of the device alone is obvious from these scores. However, again it is seen that the use of a personalized remedial program in conjunction with the NCLT results in still more improvement.

The NCLT results make one compelling point. Simply acquiring a simulator is not enough. Maximum training benefit only comes when the simulator is supported by a training technology that tells how best to use it. In this case, adding a proper training technology to an ongoing NCLT program results in an additional performance improvement which is almost as large as that found when the NCLT device alone is incorporated in the carrier landing training program.

Once proficiency in carrier landings is achieved, it is most important that it be maintained, particularly if some time elapses between landings. Any loss in capability could have disastrous results. However, we know, as seen in Exhibit 16, that there is a normal decay function for this type of performance through time. This is a matter of concern since, even in periods of shipboard deployment, there may be periods of a week or more between landings.

There now is an active program to develop low cost simulation equipment which can be used to maintain carrier landing proficiency, once it has been achieved. The objective is to use the advanced mini-computer and microprocessor technologies of today to produce small trainers which are easily transported and can be moved with a squadron and used in a ready room environment. These trainers, in which no motion would be provided, will present the necessary visual information, respond to pilot control movements, and provide automatic scoring of performance. The real attractiveness, of course, is one of economy, as shown in Exhibit 17. These trainers, which we believe will do an excellent job in maintaining carrier landing proficiency, can be acquired at a cost roughly one one-hundredth that of the more sophisticated simulators.

Conclusions

The goal of the Navy Training and Personnel Technology Program is to provide the most effective personnel support for the operation and maintenance of Navy systems. The purpose of this review is to describe the program and its objectives. Most important, this review emphasizes that the simple acquisition of new weapon systems, new training devices, or additional manpower does not in itself improve military readiness. Major improvements in our hardware and

manpower resources require corresponding advances in personnel technology. To achieve a reduction in flight hour costs, to improve the retention of aircrewmen, to increase the effectiveness of new weapons - all involve an increased commitment by the personnel and training research communities and by those responsible for program budgeting. We feel we are meeting this commitment through the development of a program which is using advanced technology and which is striving for application at an affordable cost.

Training and Personnel Technology Programs

- Training Devices and Simulators
- Human Factors
- Manpower and Personnel
- Computer-aided and Classroom Training

Exhibit 1

Training and Personnel Technology
Fiscal Summary by Major Technical Area

	$ in M		
	FY 76	FY 77	FY 78
Education and Training Technology	14	22	27
Training Devices and Simulation	12	19	25
Manpower and Personnel Technology	13	15	20
Human Factors in Weapon Systems	22	27	32
	61	83	104

Exhibit 2

Funding for Navy/Marine Corps Flight Simulator Acquisitions and Related RDT&E Costs

(Dollars in Millions)

FY	Simulator acquisition	R&D Technology[1]	R&D/Acq (%)
1976	45.7	1.8	4
1977	76.0	2.4	3
1978	126.7	2.5	2
1979(est)	128.2	2.7	2
1980(est)	120.8	2.5	2

[1] Funds represent portion of 62757N: Training and Human Engineering Technology allocated for flight simulator technology.

Exhibit 3

Ratio of R&D and Simulator Acquisition Costs

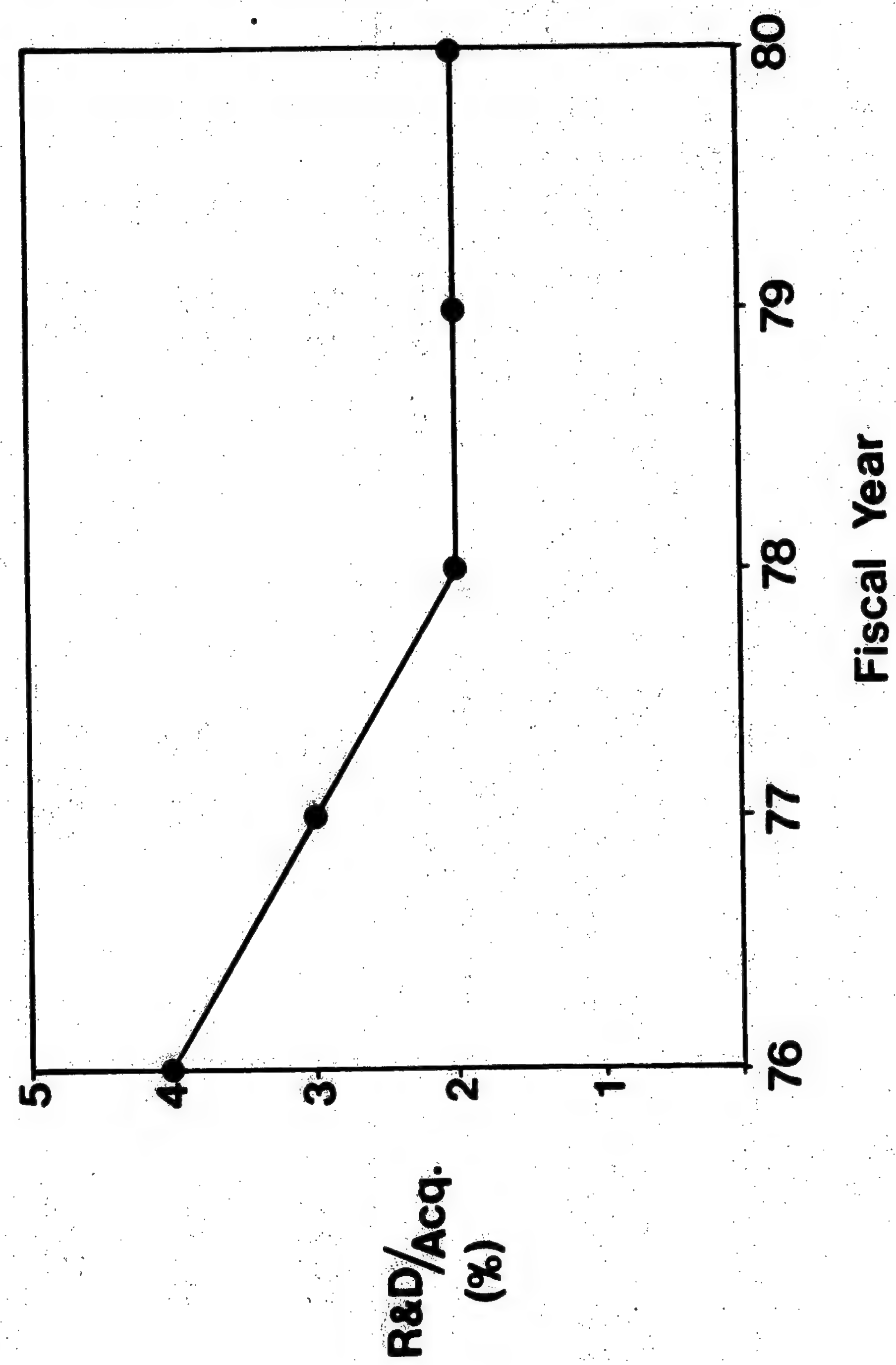


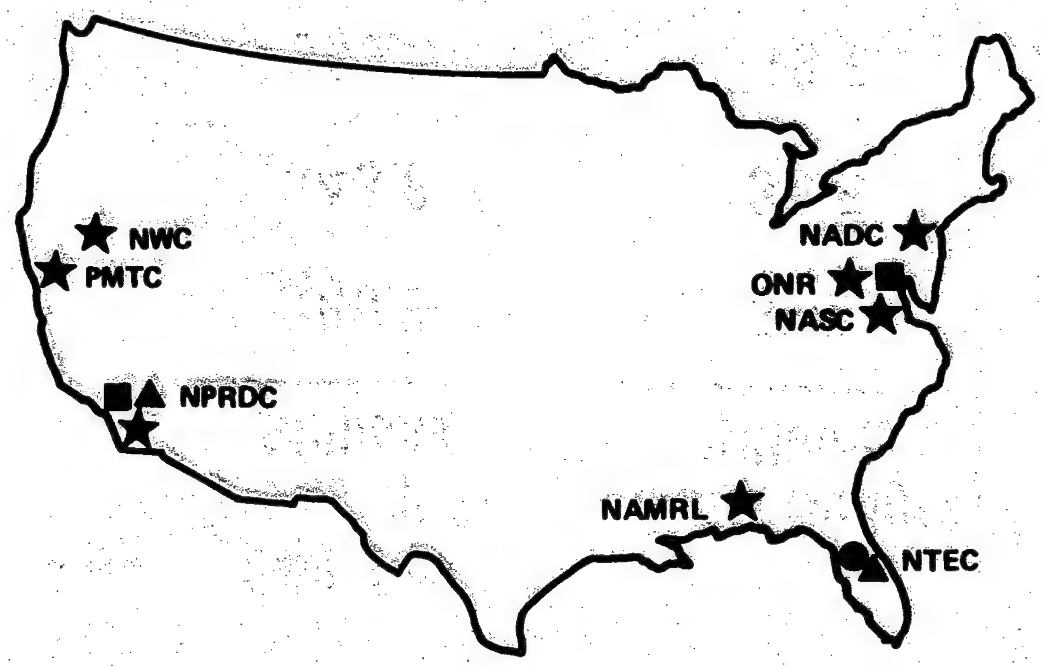
Exhibit 4

Exhibit 5

Exploratory Development Funding as a Percentage of the Total Navy and Marine Corps Budget

Year	Expl. Dev. Costs (6.2) (Millions)	Total Budget (Billions)	Expl. Dev./Budget %
1976	309.3	31.5	1
1977	343.6	36.5	1
1978	353.5	39.7	1
1979	383.7	41.0	1
1980 (est)	378.0	—	—

Navy R&D Centers for Personnel and Training Technology



● Training devices simulators ■ Manpower and personnel

★ Human factors ▲ Education and training

Exhibit 6

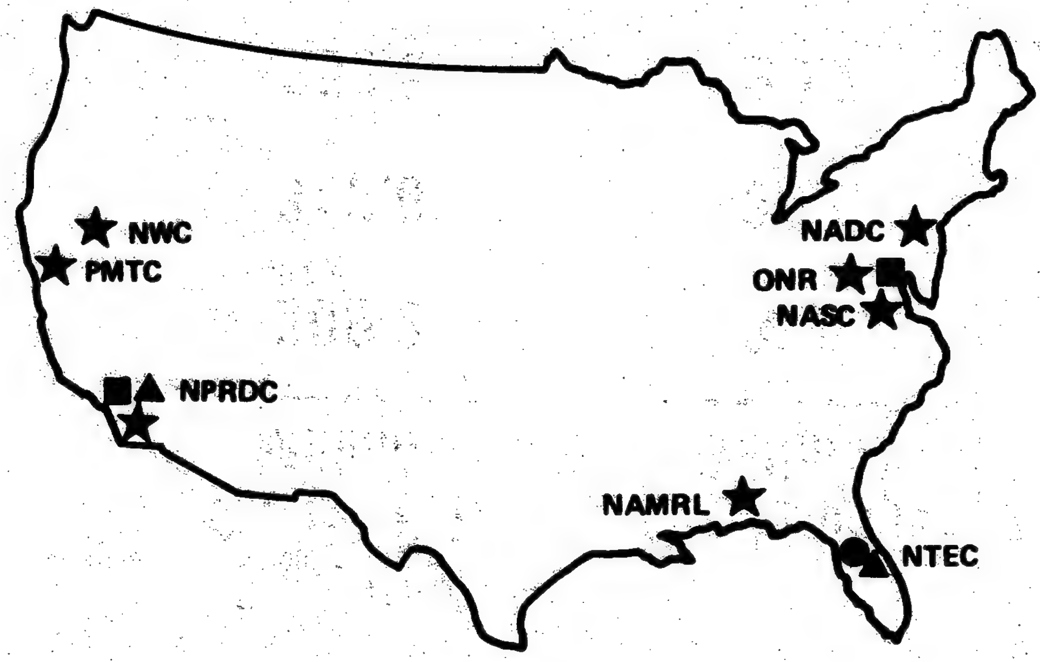
1670

Exploratory Development Funding as a Percentage of the Total Navy and Marine Corps Budget

Year	Expl. Dev. Costs (6.2) (Millions)	Total Budget (Billions)	Expl. Dev./Budget %
1976	309.3	31.5	1
1977	343.6	36.5	1
1978	353.5	39.7	1
1979	383.7	41.0	1
1980 (est)	378.0	—	—

Exhibit 5

Navy R&D Centers for Personnel and Training Technology



● Training devices simulators

■ Manpower and personnel

★ Human factors

▲ Education and training

Exhibit 6

1670

Human Resources Issues

- Increasingly-complex systems
- Critical maintenance requirements
- Decreasing personnel supplies
- Better Fleet-R&D relationship
- Pay-off demonstrations
    - Improved performance
    - Decreased costs

Exhibit 7

RDT&E Trends in Training and Personnel Technology

- Incorporation of advanced technologies
- Greater use of computers and modeling
- Greater exchange of data within human resources disciplines
- Cooperative efforts with Fleet units
- Increased Tri–service cooperation

Exhibit 8

Fleet Involvement in Training System Development for LAMPS

- **Training Committee**
  - Chief of Naval Operations
  - Naval Air Systems Command
  - Chief of Naval Education and Training
  - Atlantic and Pacific Fleet Commands
  - Navy Laboratories
- **Fleet Training Team**
  - At Weapon System Prime Contractor
- **Fleet Project Team**
- **Fleet Implementation Team**

Exhibit 9

Summary of Operating Costs per Hour for Simulators and Aircraft
(FY 1976/77 data)

Cost per hour	Median
Aircraft	$1066
Simulator	96
Cost ratio: Simulator/aircraft	0.116

Adapted from Orlansky and String, 1977

Exhibit 10

1674

Aviation Wide Angle Visual System

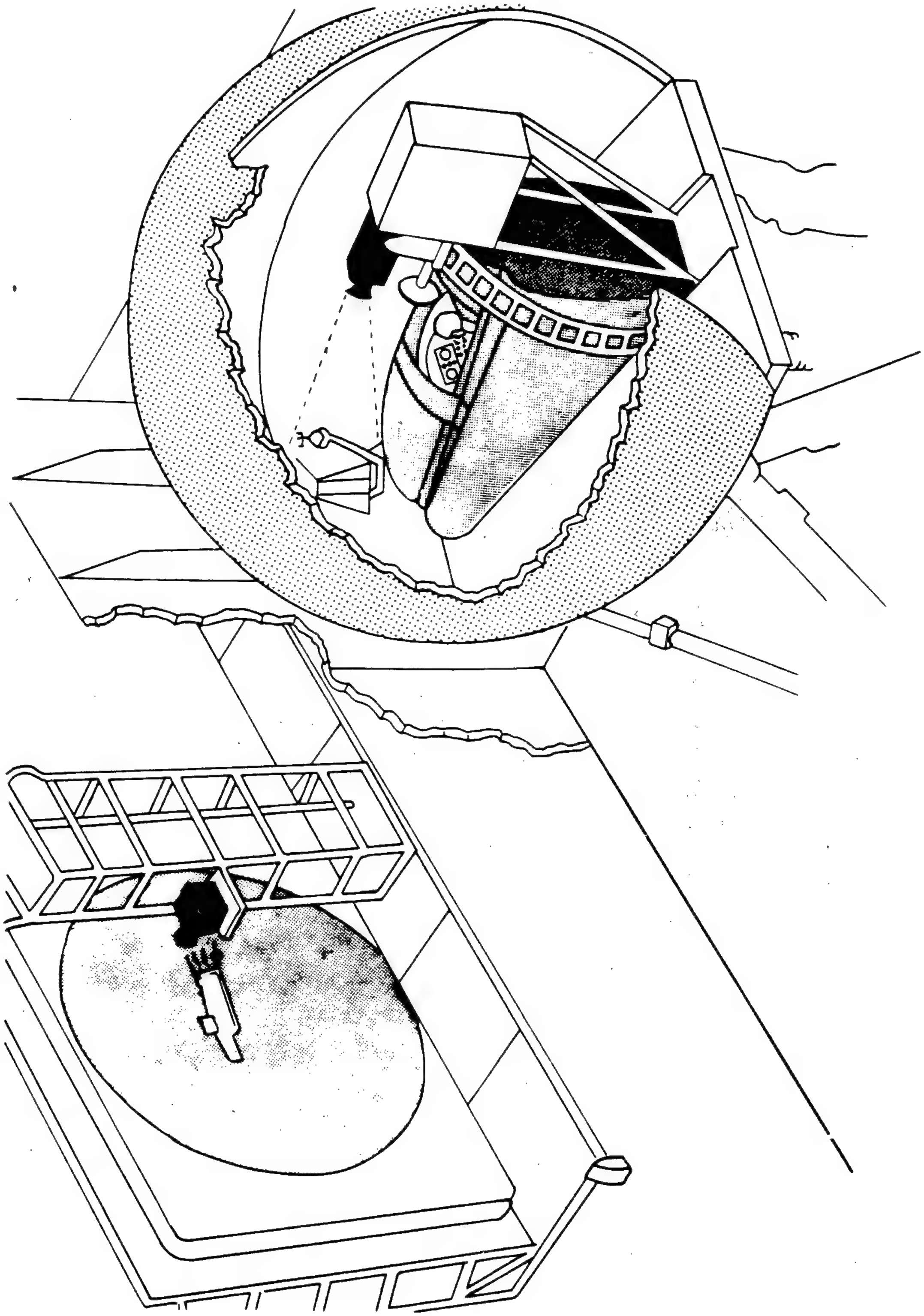


Exhibit 11

Target Acquisition Scene

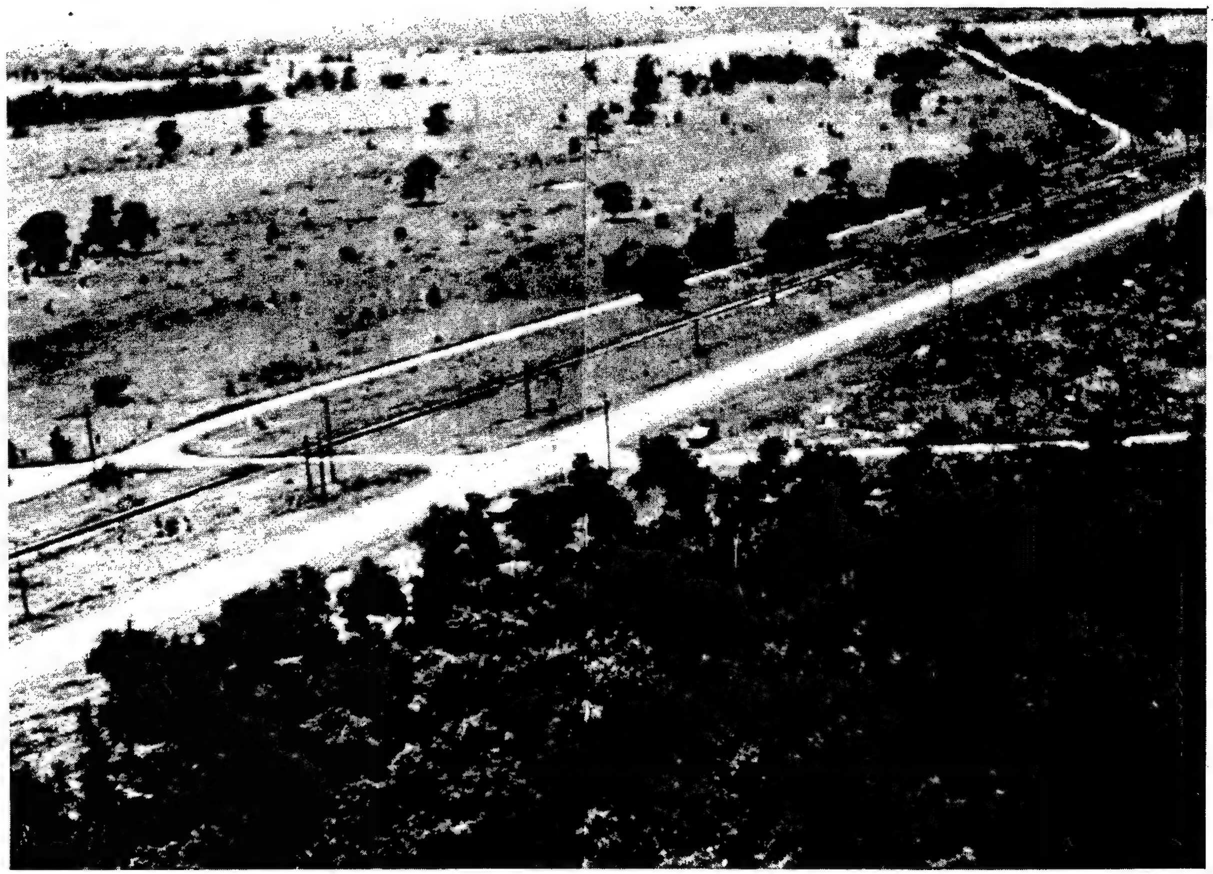


Exhibit 12

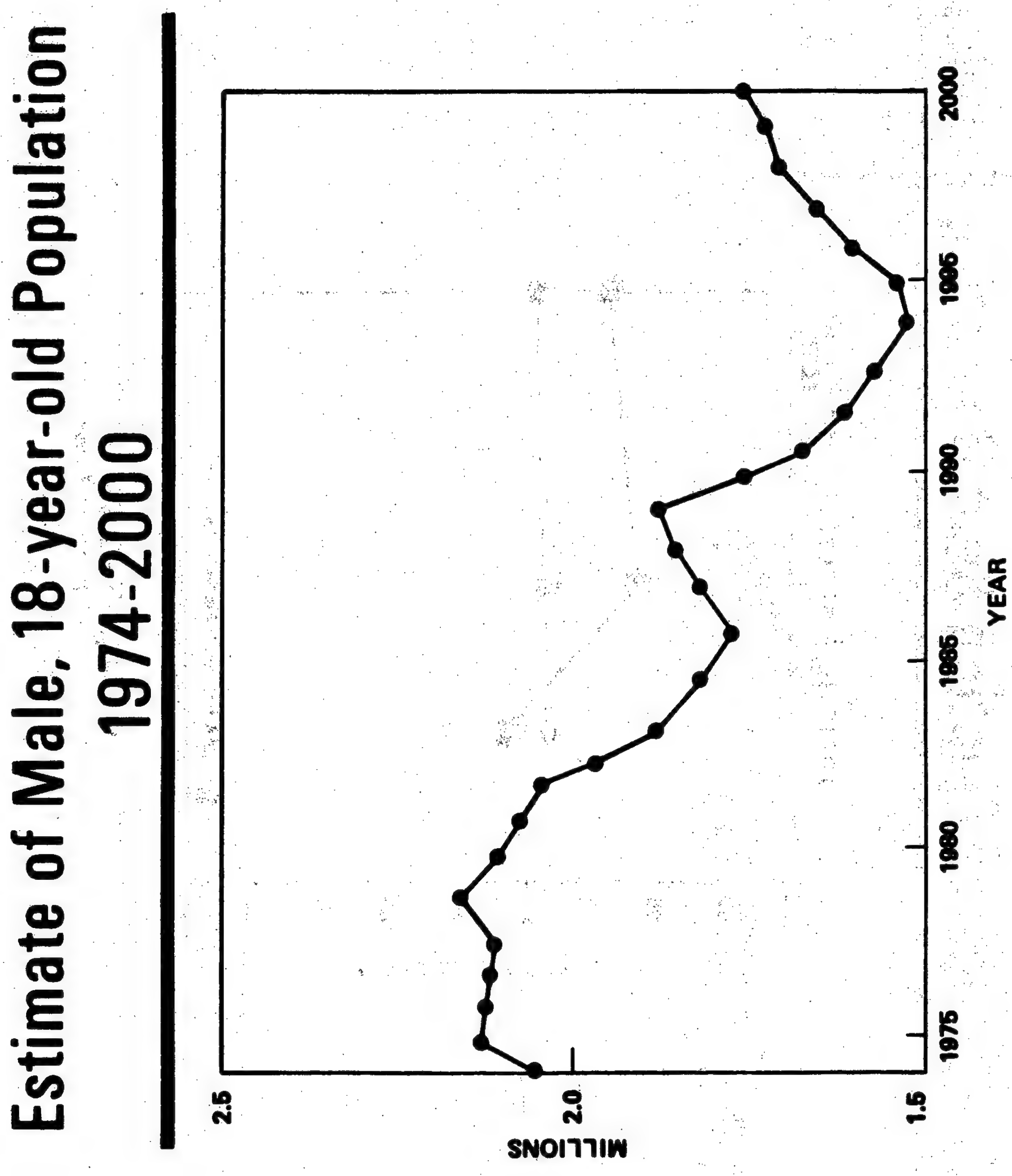


Exhibit 13

1677

Knowledge of Ejection Seat Operating Envelope

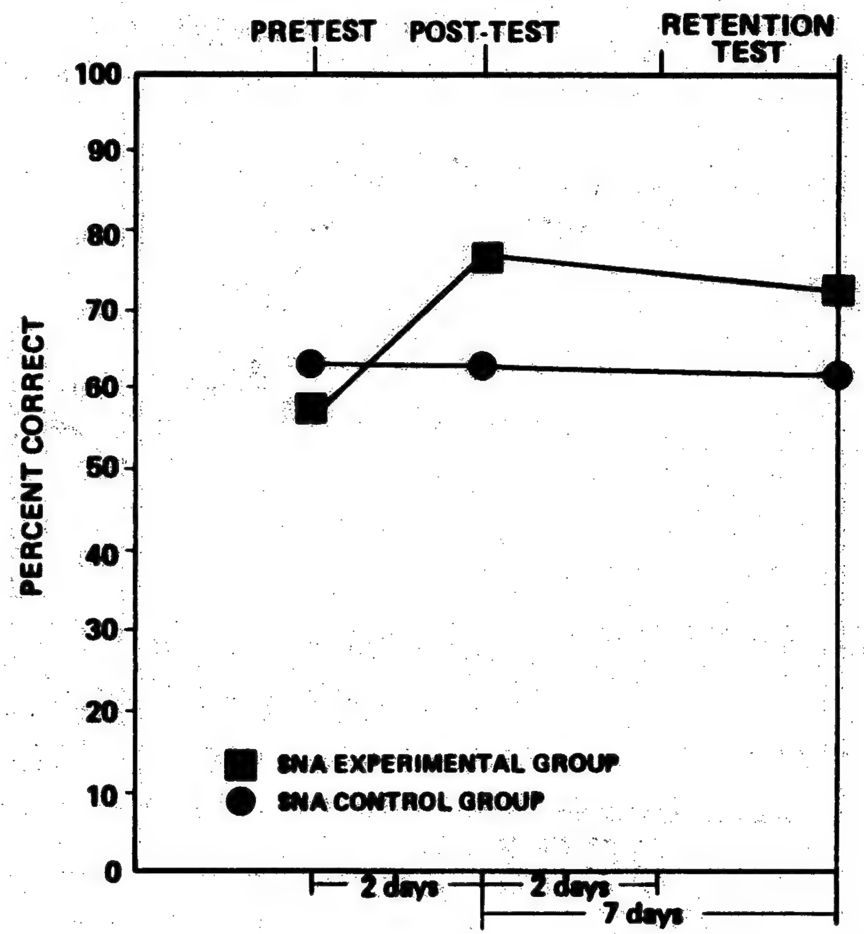


Exhibit 14

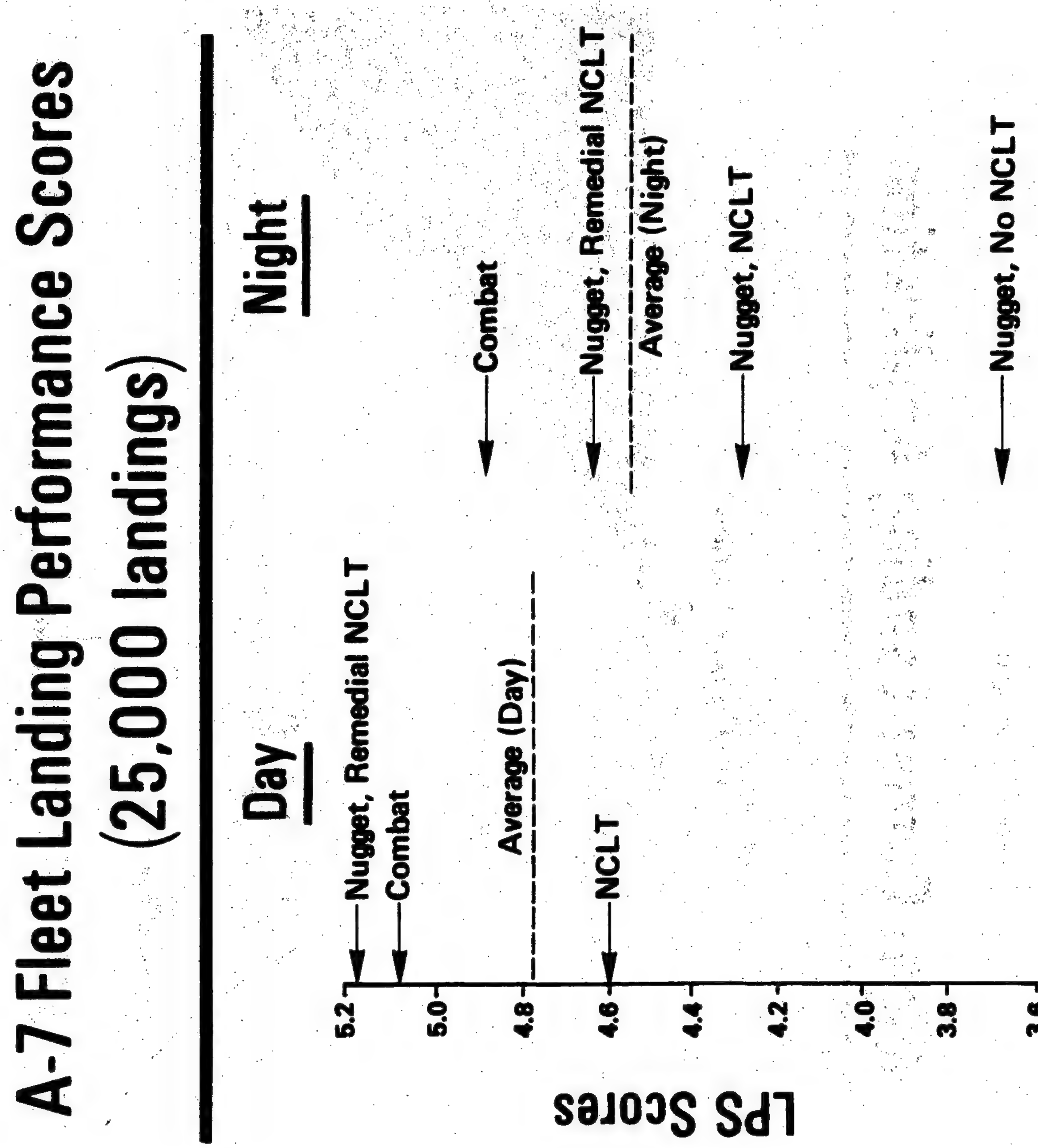

A-7 Fleet Landing Performance Scores
(25,000 landings)
Day
Night
LPS Scores
5.2
5.0
4.8
4.6
4.4
4.2
4.0
3.8
3.6
Nugget, Remedial NCLT
Combat
Average (Day)
NCLT
Combat
Nugget, Remedial NCLT
Average (Night)
Nugget, NCLT
Nugget, No NCLT

Exhibit 15

Night Carrier Landing Application

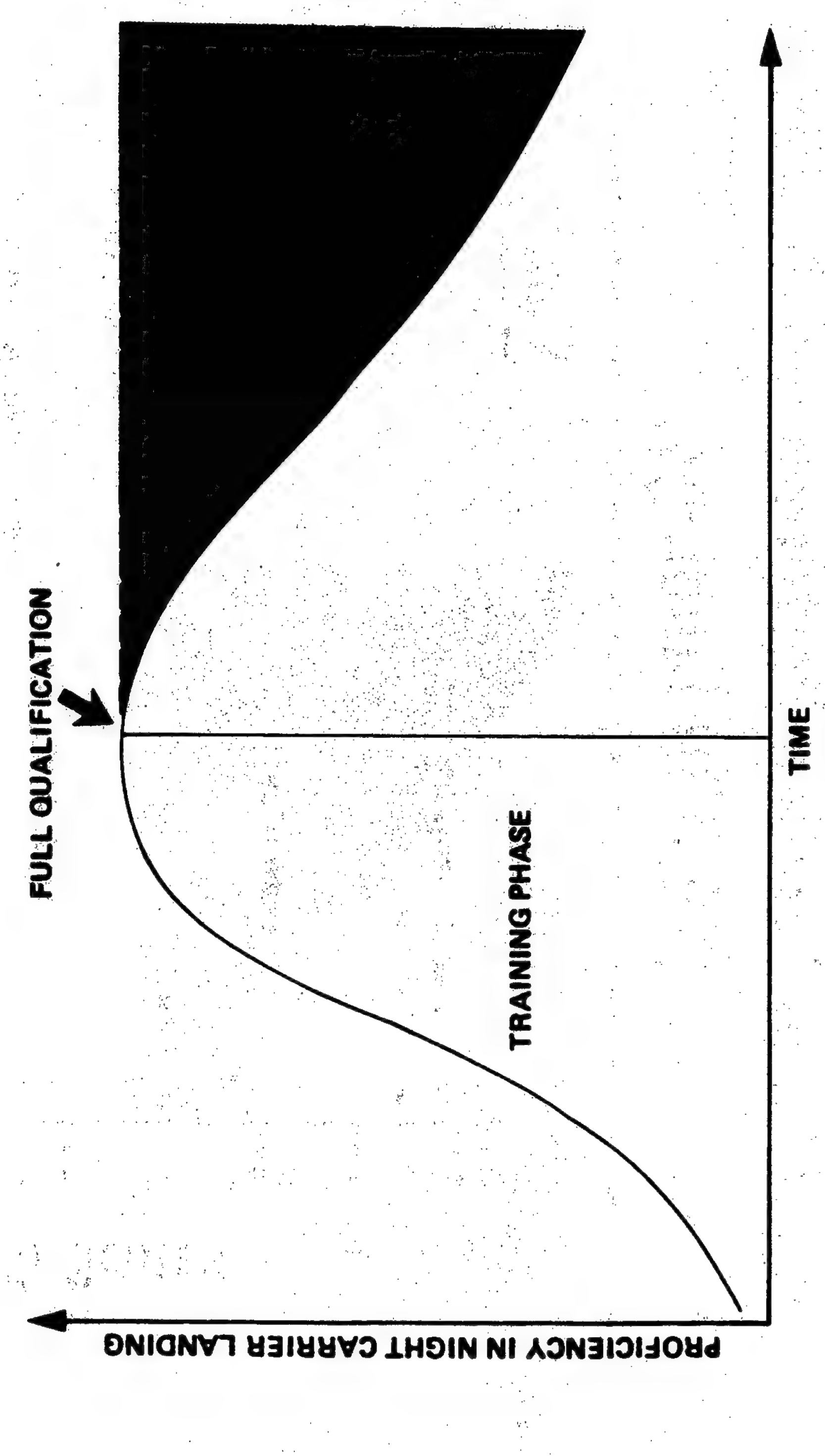
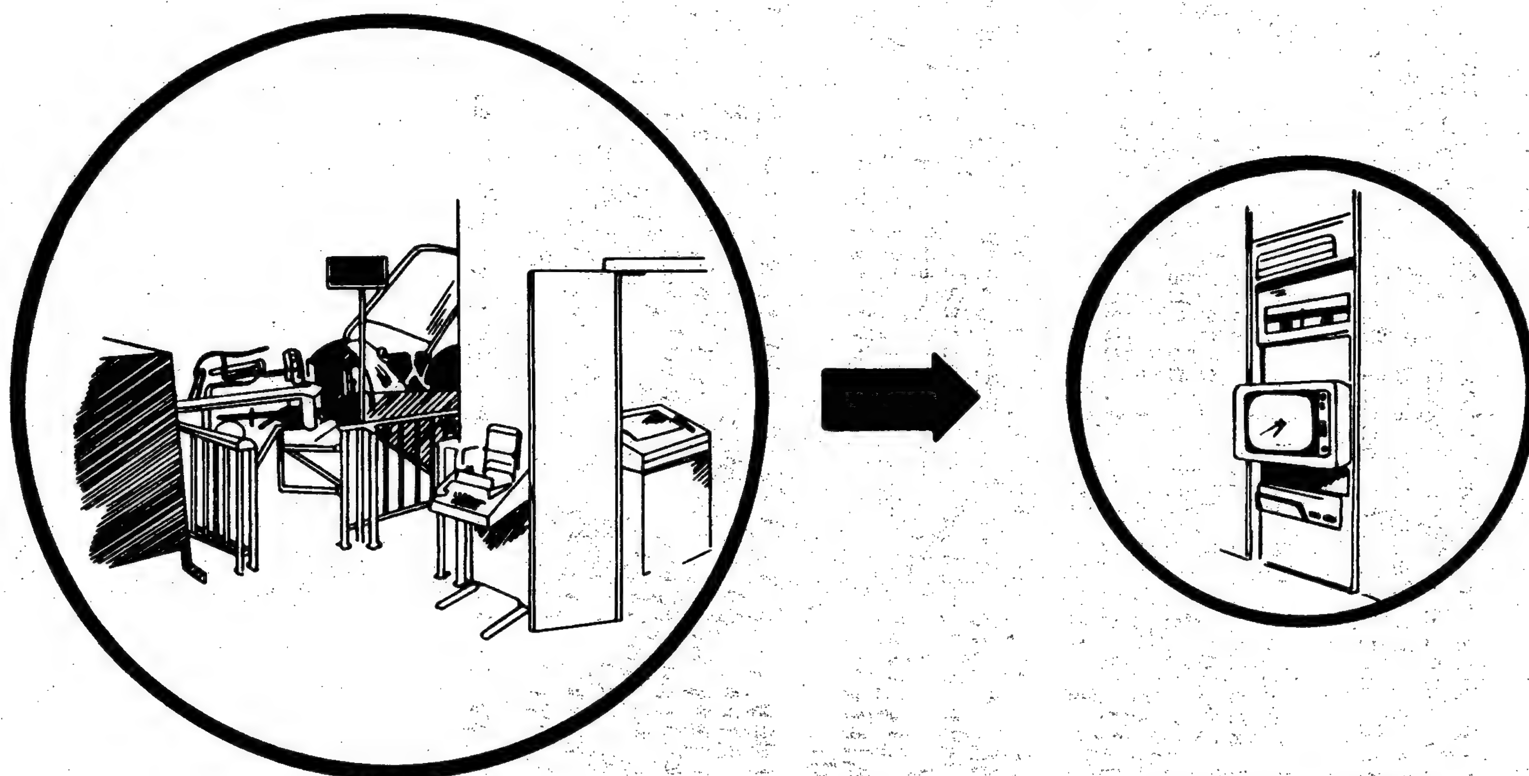


Exhibit 16

Low Cost Night Carrier Landing Trainer



Cost = 3.5M

Cost = 35K

Exhibit 17

1681

DR. JAMES F. HARVEY
Technical Director

Dr. Harvey has been Technical Director at the Naval Training Equipment Center since August 1978. Previously he served as the Director of Research and Technology from May 1976 with the collateral duty of Technical Director assigned in January of 1978.

Born in London, England, he received a B.S. degree in Chemistry in 1960 and his Ph.D. in Chemistry in 1963, both from the University of London. In addition he has completed post-graduate courses in Industrial Engineering and the Development of New Products at Northeastern University, Boston, MA. Dr. Harvey also completed the course in Executive Leadership and Management at the Federal Executive Institute in 1977.

Prior to his acceptance of the position at the Naval Training Equipment Center in 1976, Dr. Harvey held a number of senior management positions at Technical Operations, Inc., Burlington, MA; i.e., Vice President and General Manager of Advanced Technology Division; Director of Special Projects; Associate Director of Chemistry. He was also employed with 3M Research Limited in England.

Dr. Harvey is a Fellow of the Royal Institute of Chemistry, and of the AIAA. He has received the Distinguished Service Award of the Society of Photographic Scientists and Engineers. Dr. Harvey has authored papers on photographic chemistry and numerous govern- reports on imaging problems. In 1968, he served as publications chairman and in 1974 as General Chairman at the Annual Conference of the SPSE. Dr. Harvey was awarded the Navy Meritorious Civilian Service Award in June 1978.

Dr. Harvey is married and has two daughters.

LCCIM: A MODEL FOR ANALYZING THE IMPACT OF DESIGN ON WEAPON SYSTEM SUPPORT REQUIREMENTS AND LCC

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LCCIM: A Model for Analyzing the Impact of Design On Weapon System Support Requirements and LCC

Abstract

This paper describes a life cycle cost impact modeling system (LCCIM) which resulted from an effort to assess the potential impact of the Digital Avionics Information System (DAIS) concept of avionics integration on weapon system life cycle cost and system support personnel requirements. Applicable to both new and operational systems, it allows life cycle cost and human resources requirements to be used more effectively as guideline considerations within both system design and modification processes.

The LCCIM consists of three models and associated data banks which operate either interactively or independently. The first, a Reliability and Maintainability (R&M) model, is an average value model which traces and accounts for support maintenance operations at either the line replaceable unit (LRU), subsystem, or system level to produce point estimates of human resources requirements. It can also identify sources of high resource consumption and answer "what if" questions concerning the results to be expected from changing the values of R&M parameters. The second model, a Training Requirements Analysis model, examines user defined tasks and evaluates them on the basis of five task characteristic parameters. It yields detailed guidance in the establishment of system support personnel training requirements. Based on the user's selection of data inputs and choice of optional decision rules, the model identifies tasks requiring training, generates a suitable training plan, and specifies a feasible training program. The third model is a System Cost model which aggregates the components of system life cycle cost and presents them either in selective combination or summary form.

1684

BACKGROUND

Confronted with a reduced budget, increased operations and support (O&S) maintenance costs, and a volunteer force, the Air Force is recognizing the need to reflect these considerations in the systems acquisition process. In the past, the acquisition of a major system has taken from 10 to 17 years. The process has been basically "open-loop" in the sense that actual assessment of O&S costs only occurred after the system was deployed. Even if design or support improvements could be found then, the retrofit bill was often prohibitive.

This research was undertaken in response to the need to discipline the systems acquisition process, particularly for avionics systems. The fundamental objective was to develop a method for "closing the loop" to influence avionics system design based upon downstream life cycle cost and system support personnel requirements. A literature search was conducted to determine the availability of suitable models. It confirmed that hundreds of LCC models do, indeed, exist. However, almost without exception, they apply cost factors to the expected values of the system variables and aggregate the cost elements to determine total LCC.

In addition to their non-analytical nature, the ineffectiveness of these models in actually reducing system LCC can be traced to the fact that they were often applied in evaluations which can only be described as post hoc. These evaluations assessed system LCC after the fact, lending little insight to means for cost avoidance. In many instances, life cycle cost studies merely amounted to cost accounting. In all fairness, it must be mentioned that design-to-cost concepts were sometimes employed in an effort to reduce acquisition costs. Unfortunately, without consideration of logistics support costs, design-to-cost as it was previously applied, often opposed the life cycle cost goals it was intended to promote. Furthermore, there had been no comprehensive planned approach to develop and apply cost avoidance ideas early in the systems acquisition process, when such information could be acted upon to result in real benefits.

In brief, a need was identified for: (1) a modeling system and associated data banks capable of determining system LCC analytically, on an a priori basis; and (2) a

method for "closing the loop" to apply life cycle cost and system support personnel requirements considerations at each phase of the systems acquisition process. The fundamental goal of this paper is to describe the LCCIM: a means for influencing the design of the entire integrated system in terms of both operational effectiveness and LCC. This viewpoint recognizes both the system design and the total operation and support system.

APPROACH

A systems approach was taken to develop the LCCIM. By systems approach, we mean that the following basic steps were taken: (1) the problem objective was stated at the highest level; (2) interactions between the major total system elements were identified; (3) transfer functions between various input and output variables were defined; and (4) elements that the designer can change were modeled in terms of their influence on the overall system.

The highest level problem statement for the LCCIM is given in Figure 1. The task is to influence selection between acceptable alternatives for: (1) system designs, (2) support concepts, and (3) training and aiding policies based upon LCC considerations. To formulate the problem, the overall objective function was taken as: Minimize LCC subject to a specified effectiveness constraint.

The main objective of life cycle costing is to consider system ownership as well as acquisition costs, in order to provide a comprehensive visibility into the relative economic advantages of alternative designs. In order to meet this objective, decision making criteria pertinent to each phase of the systems acquisition process must be generated on the basis of data available at that point in time. Clearly, a requirement exists for more comprehensive models to identify the ownership cost drivers within emerging systems and portray their interactions. Data in the human resource areas of manpower, training, technical documentation, and support equipment need to be provided earlier and in more detail to allow for a timely and accurate estimation of ownership costs. Most importantly, the model(s) must be capable of operating on the data that is available early in the system acquisition process to provide cost estimates at that particularly critical time. The hierarchy of life cycle costs utilized for the development of the LCCIM is shown in Figure 2.

The major system elements which drive the LCCIM cost hierarchy were taken to be: (1) the avionics system design characteristics, (2) the operating and support requirements dictated by the particular design configuration, and (3) the training and aiding policy necessary to provide the required personnel skills and knowledge for operation and maintenance. An overview of the procedure utilized to quantify the interrelationship between these major system elements is given in Figure 3. The five steps shown there are: (1) functional, (2) maintenance, (3) reliability and maintainability (R&M), (4) training, and (5) cost analyses. Basically, the equipment drives the maintenance requirement; the reliability determines the demand on the maintenance system; the equipment characteristics, R&M parameters, and manpower determine the required resources and associated skills and knowledge requirements; the training program, associated job aids, support equipment, and appropriate manpower provides the required support capability; and the cost analysis identifies the specific costs associated with each element previously shown in Figure 2. Each step is now described in some detail.

A generic model for avionics suites was constructed based upon the functional requirements for a representative close air support (CAS) mission. It was determined that the following functional groups of equipment were required: navigation, communications, counter-measures, air-to-ground attack, control and display, and flight control. The process of its construction is fully described in AFHRL-TR-76-59, Mid-1980s Digital Avionics Information System Conceptual Design Configuration. An equipment hierarchy was then established to describe a generic avionics suite. The levels in the hierarchy consist of system, functional group, operational function, subsystem, and LRU. Following this, a coding system was assigned so that each element in the generic avionics suite could be rapidly identified and indexed. Figure 4 illustrates the technique by showing a portion of the equipment hierarchy. For example, the highest indenture denoting system level (avionics) is coded in the first space of the code designation (A). The functional group (e.g., communications) is coded in the second space (AC), and so on. Thus the equipment hierarchy of any avionics suite, or system, can be described on a common basis which allows it to be modeled.

The next step was to model the operational and maintenance process. The initial approach taken was to simulate the detailed O&M process shown in Figure 5, using a Monte Carlo simulation model called the Logistics Composite Model (LCOM). However, due to a need for computational speed and a requirement that the model be operable on data of lesser detail than that required for the LCOM, the R&M model was developed. It is based on a simplified representation of the O&M process as shown in Figure 6. It should be noted that the operational scenario and the maintenance environment are modeled separately. Basically, the operational scenario is modeled as creating a demand upon the maintenance system as a function of the number of sorties flown (or of flying hours) and the failure rates of the individual equipments in the avionics suite. The R&M model computes the demand placed on the maintenance system on an LRU-basis and then aggregates to determine the total demand. Therefore, the R&M model treats the operational scenario in terms of the mean flying hours between maintenance actions of individual LRUs. This mean value of demand on the maintenance system is sufficient for assessing support resources during the conceptual phase of the acquisition process and is, in all probability, the best figure which can be generated on the basis of data available during that time period.

Given that a demand is placed upon the maintenance system, the maintenance process must restore the equipment to operational readiness. This is accomplished by minor on-aircraft repair or by replacement with an operationally-ready LRU. However, since total support resources must be estimated, the R&M model must also provide estimates of the resources required for the repair of the LRUs in the shop.

The basic approach was to determine all possible maintenance outcomes or events that could result from a specific equipment failure. Each maintenance event places a demand on the maintenance system. The average resources demanded by each maintenance event are determined on an LRU-basis, e.g., maintenance crew composition, support equipment, and time. Finally, the probability of each specific maintenance event occurring (per sortie or per 1000 flying hours) is introduced. Total support resources per LRU are determined by multiplying appropriate probabilities by the support resources associated with each maintenance event. Required support resources are then computed by LRU, subsystem, functional group, and total system by summing across the appropriate levels in the equipment hierarchy.

Later in the systems acquisition process when more detailed data concerning system design and operational utilization become available, the LCCIM user may wish to substitute the previously mentioned LCOM in place of the R&M model within the LCCIM. This will enable him to examine more closely the critical drivers of cost and operational availability identified by the R&M model. It will also allow him to account for peak loads, saturations, queues, or other nonlinear constraints that exist in the actual maintenance environment but, are not picked up by the average value process of the R&M model.

The R&M model described above provides a means for computing the required support resources for a particular system design or support concept alternative. The next step in the LCCIM procedure to quantify the interaction of major system elements addresses maintenance support personnel training requirements. In order to assess the impact of system design, operation, and support on training requirements, a training requirements analysis model and associated data bank were developed. The model allows a training analyst to assign values to variables describing systems, policy, training operations, resources, and cost. Within the bounds of the user established set of constraints, it produces an estimate of the training program requirement which their interactions generate. Results may be refined by iteratively exercising the model using different values for constraint parameters and/or input data. The means to relate system/policy/resources/cost input data to resultant training impacts are contained in the model, and it is programmed for both user interactive operation via remote terminal facilities and batch operation.

The training model, Figure 7, consists of three modules: a pre-processor, and two analytical modules for training plan and training program generation.

Operation of the model is predicated upon the establishment of a data bank containing the set of tasks to be learned. Their level of specificity is a user defined variable, allowing for the flexibility of task definition. Each task, however, is assigned five descriptor values denoting: frequency, criticality, learning difficulty, taxonomy, and sequencing.

The data bank is inputted to the pre-processor module which screens the total set of tasks, in a series of go

no-go decisions, to select those which require training. The selected tasks then become the subset of tasks that are the training requirement. The selection is based upon pre-established descriptor value levels determined by the user. For example, a criteria of tasks of a difficulty level above .60 may be used to discriminate between tasks on the basis of that parameter. Thus, the user maintains control of the decision process by his selection of decision criteria, i.e., parameter combinations and parameter value cut-off points. The list of tasks which the pre-processor determines to be requirements for training retains its associated set of descriptor values and becomes the input data set for the first analytical module which is the training plan generator.

At this point, it is assumed that all of the outputted tasks are to be trained. The user now has the option of designating a value for any one of three constraining conditions: personnel required (number); maximum allowable training cost (dollars); or maximum allowable training time (months). He need, however, only specify the training personnel requirement to operate the module using internalized data and relationships. The training plan generator then produces an initial training plan. This is a two step process in which a minimum cost school/on-the-job training (OJT) mix is determined, followed by recommendations concerning appropriate methods and media, e.g., lecture, simulation, mockups, actual equipment, etc.

After reviewing the initial training plan, the user may either select a different set of decision criteria and exercise the training plan generator module to obtain another training plan, or continue on to the second analytical module to generate a training program. Generally, the training plan generator will be iterated several times by the user as an investigative/optimization procedure prior to the selection of a training plan to be examined in more detail. To facilitate this kind of activity, all modules of the training requirements model are programmed for user interactive operation via remote terminal facilities, as well as for batch operation.

Having provided for the computation of support resource requirements and training program definition, the last step in the LCCIM procedure is the assignment of appropriate cost factors for each variable. Referring again to Figure 2, each cost element in the hierarchy must be quantified and aggregated to evaluate the total cost impact of

alternative system designs and support concepts under evaluation. This is accomplished by means of a system cost model component of the LCCIM which is both user interactive and operable interactively with the R&M model via remote terminal facilities, and operable either singly or interactively with the R&M model in a batch processing mode of operation.

The systems approach employed by the LCCIM consists of a structured process that provides for the efficient use of available information. That process recognizes the incompleteness and inexactitude of the data existing during the conceptual phase of the systems acquisition process that must, however, be used to forecast outyear resource utilization and cost. Within it a statement of the basic need for the weapon system leads to the identification of the most comparable reference system; modification of reference data to reflect technological advances and advanced O&S concepts produces baseline input data for the LCCIM; and those data are then processed to determine resource utilization in terms of man and machine requirements.

SUMMARY

The LCCIM provides a powerful analytical tool which is particularly suited to an investigative role in determining how to guide the design and support of systems to achieve essential capabilities at affordable cost. This is true throughout a system's life cycle, from conception and including outyear modification. As greater system definition data become available the LCCIM can transition from its basic impact mode of operation to one which enables the detailed analysis of system cost and requirements.

An overview of LCCIM operation is given in Figure 8. The total system combines the R&M, training requirements analysis, and system cost models to assess the LCC impacts of various design, support, and training alternatives. Operable in either an interactive or batch processing mode, the ability of the LCCIM to be effectively used iteratively by the system designer allows for systematic assessments of relevant objectives and trade-off studies of alternative designs. The model outputs are presented in formats which provide general (top down) and detailed (bottom up) perspectives, as well as visibility at the intermediate levels of system cost and resource impact assessment.

Outputs are developed by aggregating resource utilization, applying cost factors, and grouping/ranking measures of impact (MOI) such as maintenance manhours per flighthour or flightline service availability. High resource impacts located at the top of the MOI lists can be identified as areas in which changes can produce significant payoffs in cost avoidance. Output data can be examined at various levels of detail to identify dominant resource and cost drivers. Sensitivity analyses can be conducted within the modeling system to measure the effect of interrelationships among model parameters.

After identifying dominant drivers and determining parameter sensitivities, the LCCIM can be used to choose between "finalist" candidate design alternatives which are "tuned up" versions of alternatives evaluated previously by the LCCIM. These could represent either single subsystems, modified on the basis of information provided by the LCCIM, or a composite of such subsystems. In this final step, all parameters affected by the revision of alternatives would be changed accordingly and the LCCIM would be operated as a unit to provide a final total LCC comparison. Thus, the trade-off process can be followed to completion in comparing major system alternatives as well as in making a series of gradual parameter changes that lead to a set of design or support planning characteristics that best satisfies the basic need at an affordable cost.

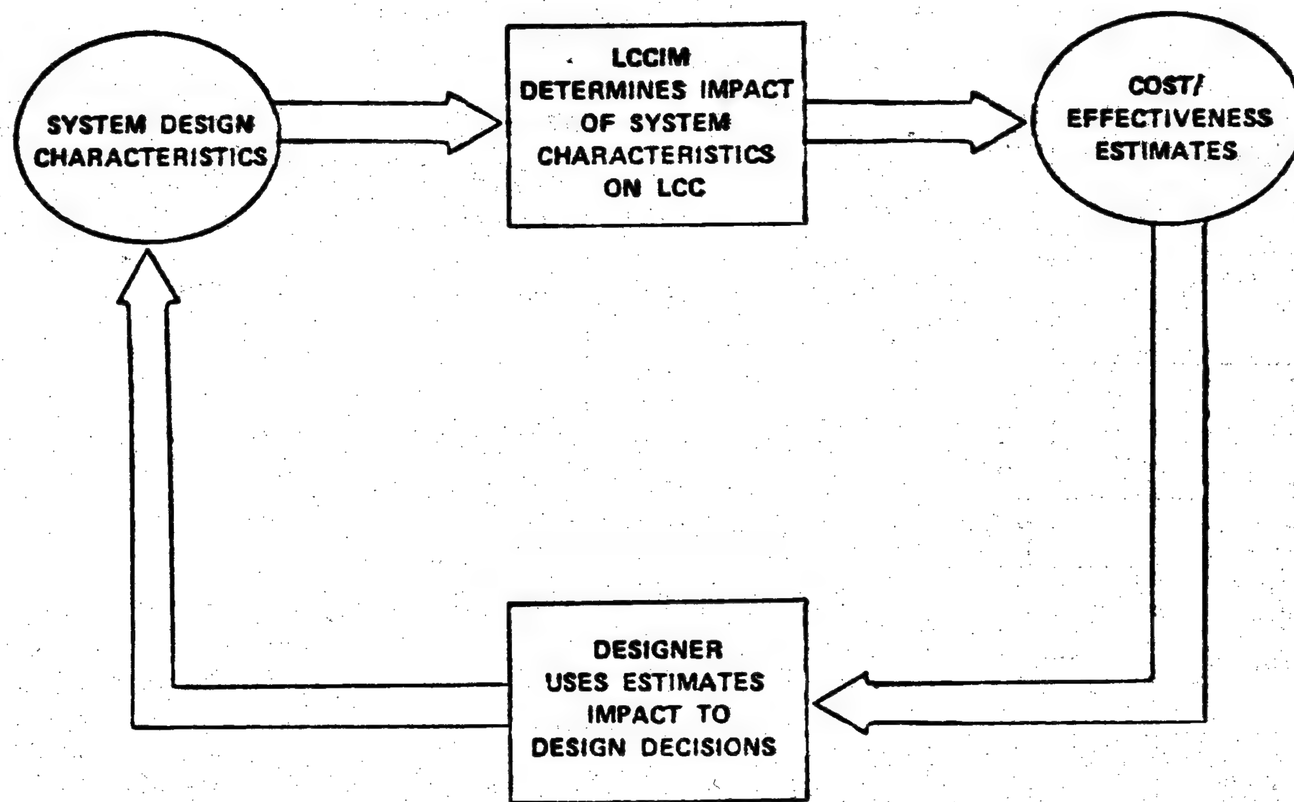
BIOGRAPHICAL SKETCH

Mr. Baran is a Research Psychologist in the Advanced Systems Division of the Air Force Human Resources Laboratory. He is also the Division Focal Point for Economic and Cost Analysis and serves as a Liaison Deputy Director of the Digital Avionics Information System (DAIS) program in the Air Force Avionics Laboratory. He was formerly a Research Psychologist in the Human Factors Department of the Electric Boat Division of General Dynamics Corporation in Groton, Connecticut. He received undergraduate degrees in psychology and engineering from Clark University and Mitchell College respectively, and has completed thirty semester credits of graduate work at Tufts University and the University of Connecticut.

Since becoming a civilian employee of the Air Force in 1971, Mr. Baran's primary concern has been the development of means to assess new weapon system support requirements and life cycle cost such that human resources considerations can be more fully incorporated in the systems acquisition process. Publications in this area consist of five papers and eighteen technical reports. He is a member of the Human Factors Society and is licensed to practice psychology in the state of Ohio.

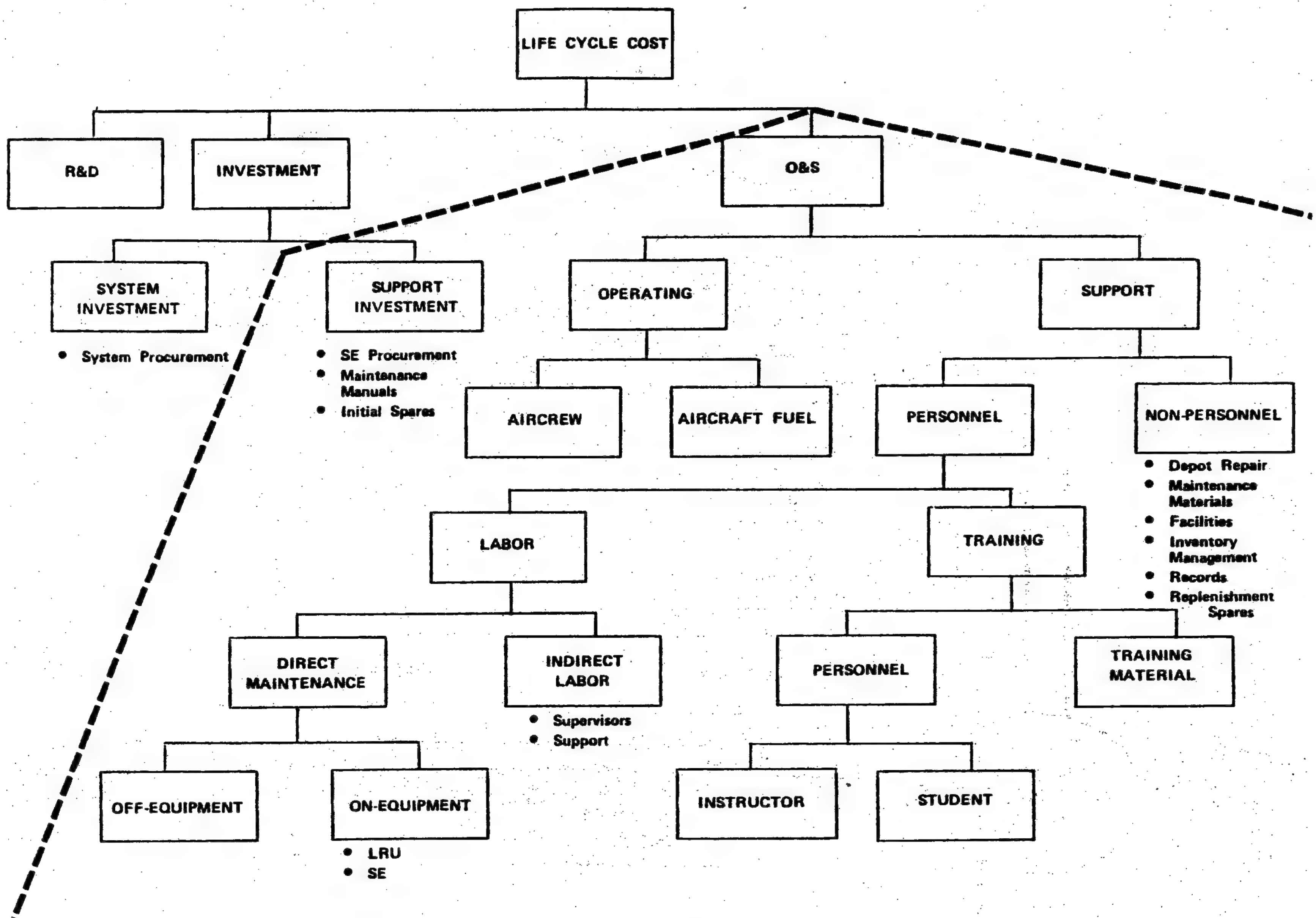
Dr. Czuchry received his PhD from the University of Connecticut in 1968. He is a member of the senior staff and is currently serving as Director, Advanced Systems for Dynamics Research Corporation. Dr. Czuchry developed a total systems approach for solving a broad spectrum of logistics and human resource problems. He has been a major contributor on more than 20 military and civil programs. He has 14 publications and more than 25 Government technical reports. He received the USAF Systems Command Technical Achievement Award in 1973. He has also received six other engineering achievement awards.

Mr. Goclowski received a BSEE from the University of Massachusetts in 1955 and an MSEE from Northeaster University in 1965. He joined Dynamics Research Corporation (DRC) in 1965 after working as senior project engineer on the design and development of inertial guidance and navigation systems at AC Electronics and United Aircraft Corporation. He also has experience, as a United States Army officer, in instructing tri-service and civilian personnel in the assembly and test of atomic weapons. As the Manager of Advanced Military Systems at DRC, Mr. Goclowski is currently responsible for the following study contracts: the Digital Avionics Information System (DAIS) Life Cycle Cost Study, Personnel Availability Analysis Study, and the Coordinated Human Resource Technology Study for the Air Force Human Resources Laboratory; the Prototype HARDMAN Study for the Chief of Naval Operations; and an Integrated Personnel System Cost/Effectiveness Study for the Naval Personnel Research and Development Center.



USE OF LIFE CYCLE COST CONSIDERATIONS TO INFLUENCE DESIGN

Figure 1



HIERARCHY OF LIFE CYCLE COST

Figure 2

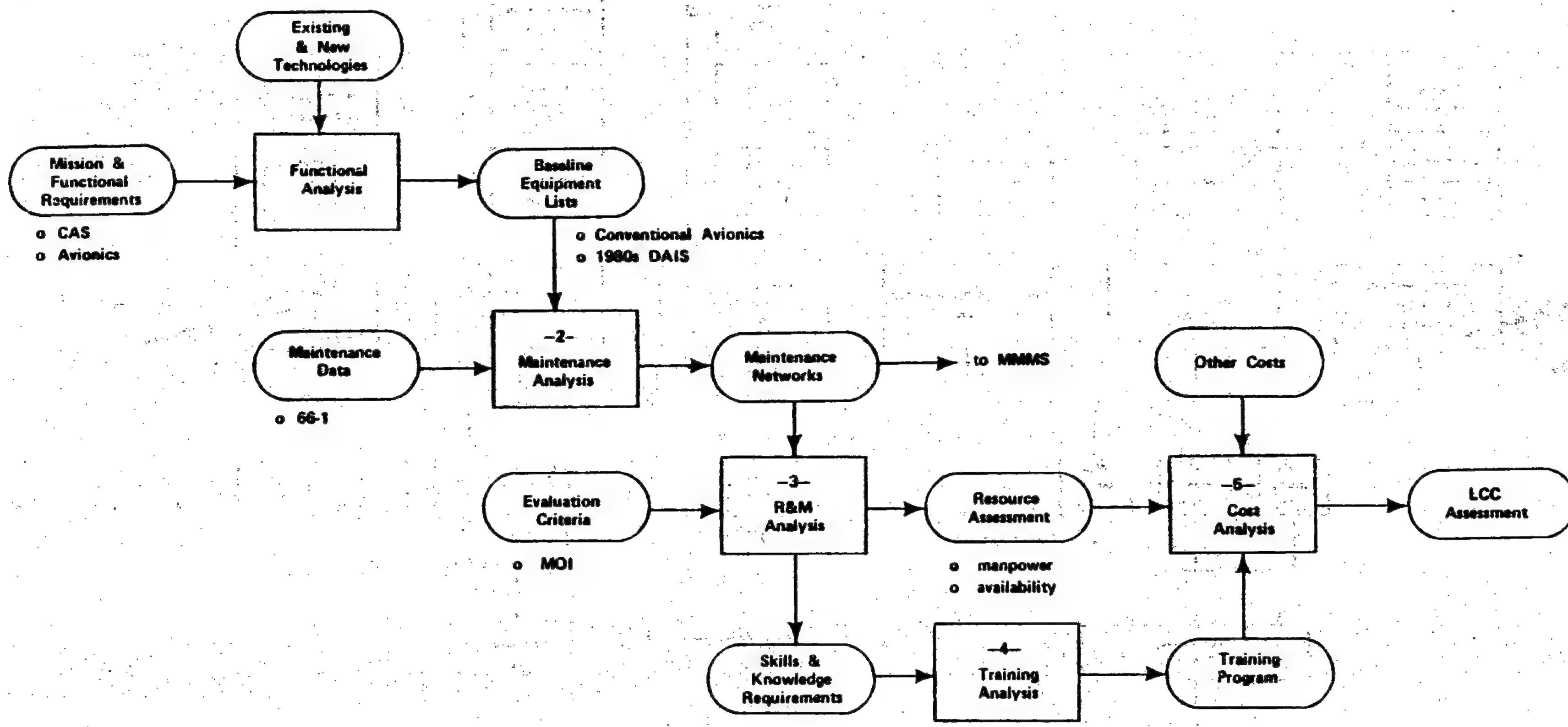


Figure 3 RELATIONSHIP BETWEEN MAJOR SYSTEM ELEMENTS

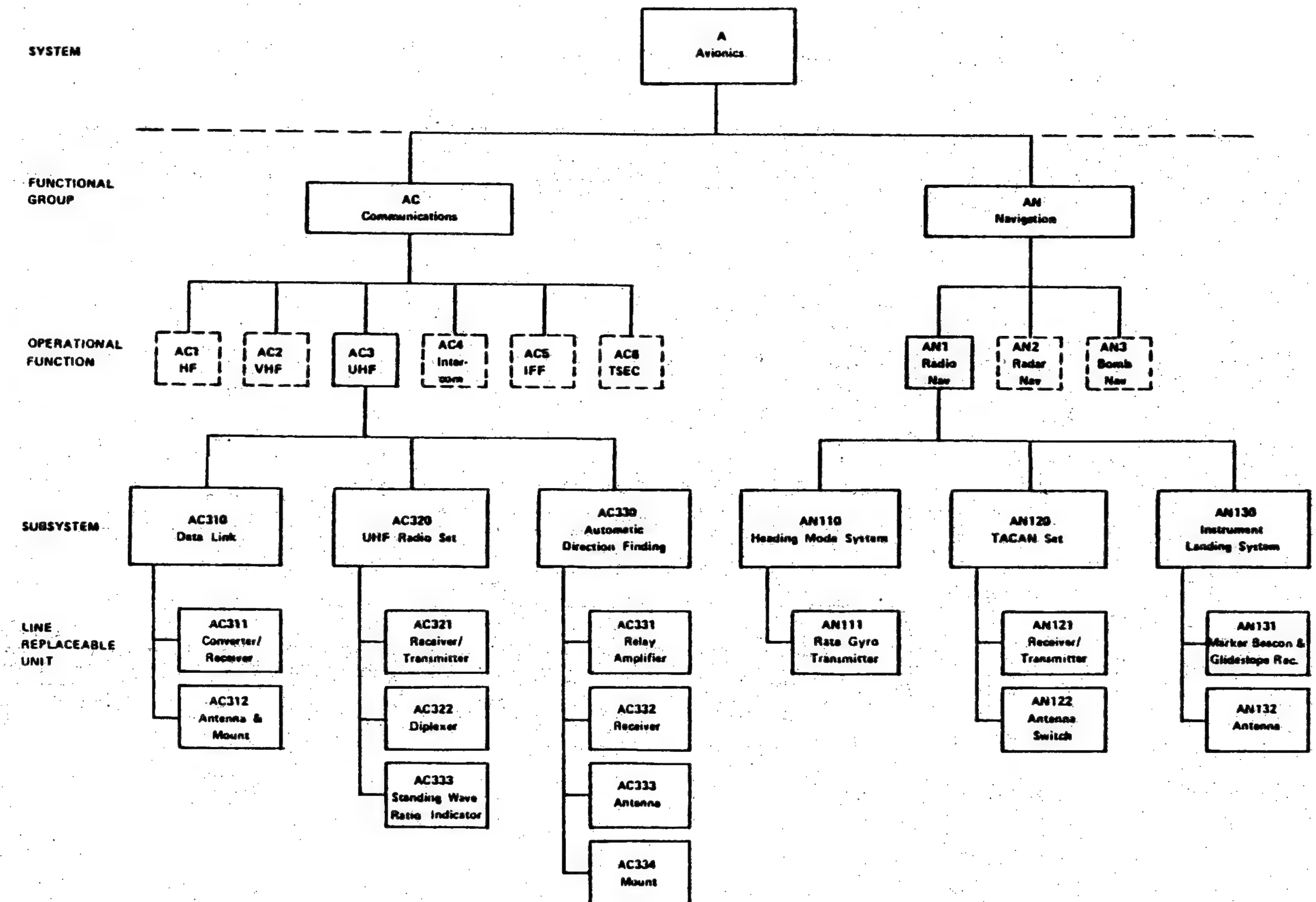


Figure 4 EQUIPMENT HIERARCHY STRUCTURE

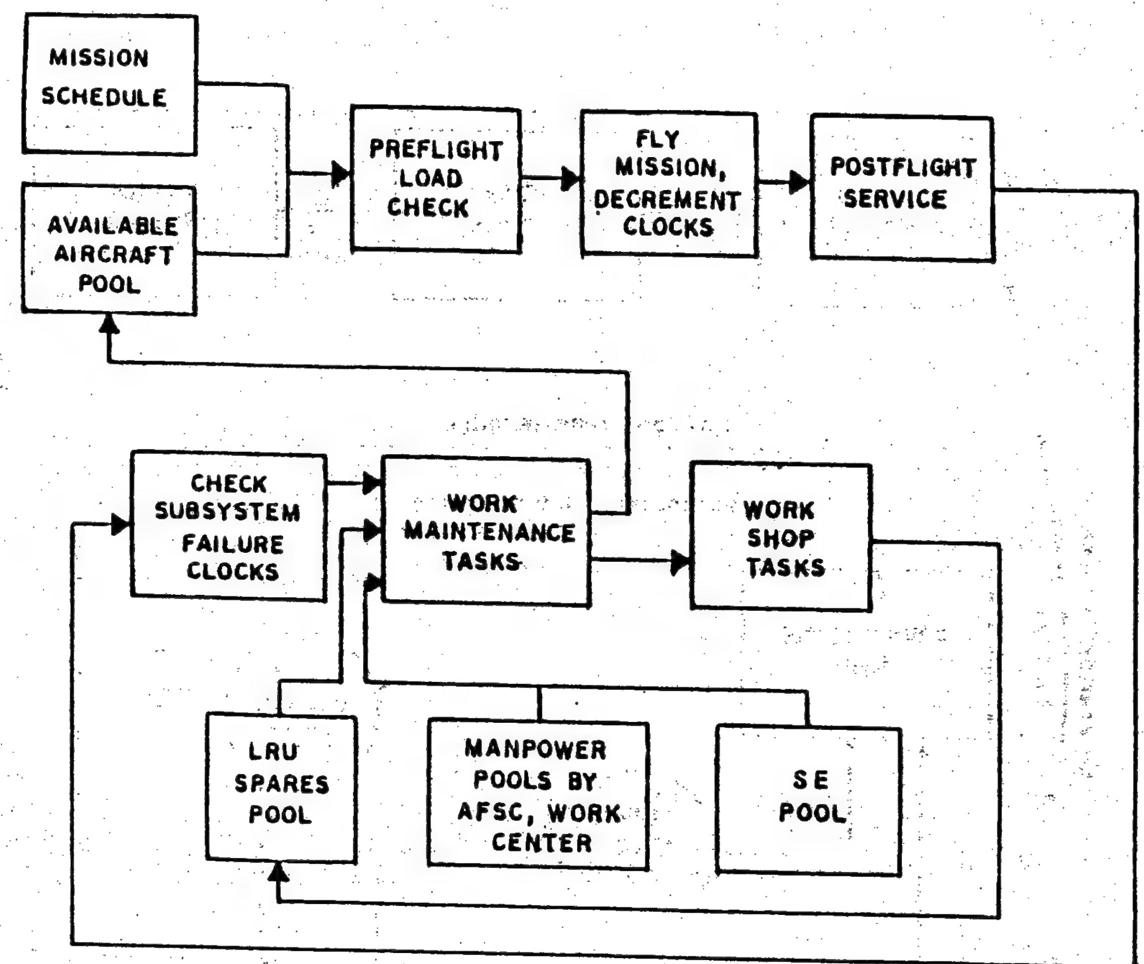


Figure 5 OPERATIONS AND MAINTENANCE PROCESS

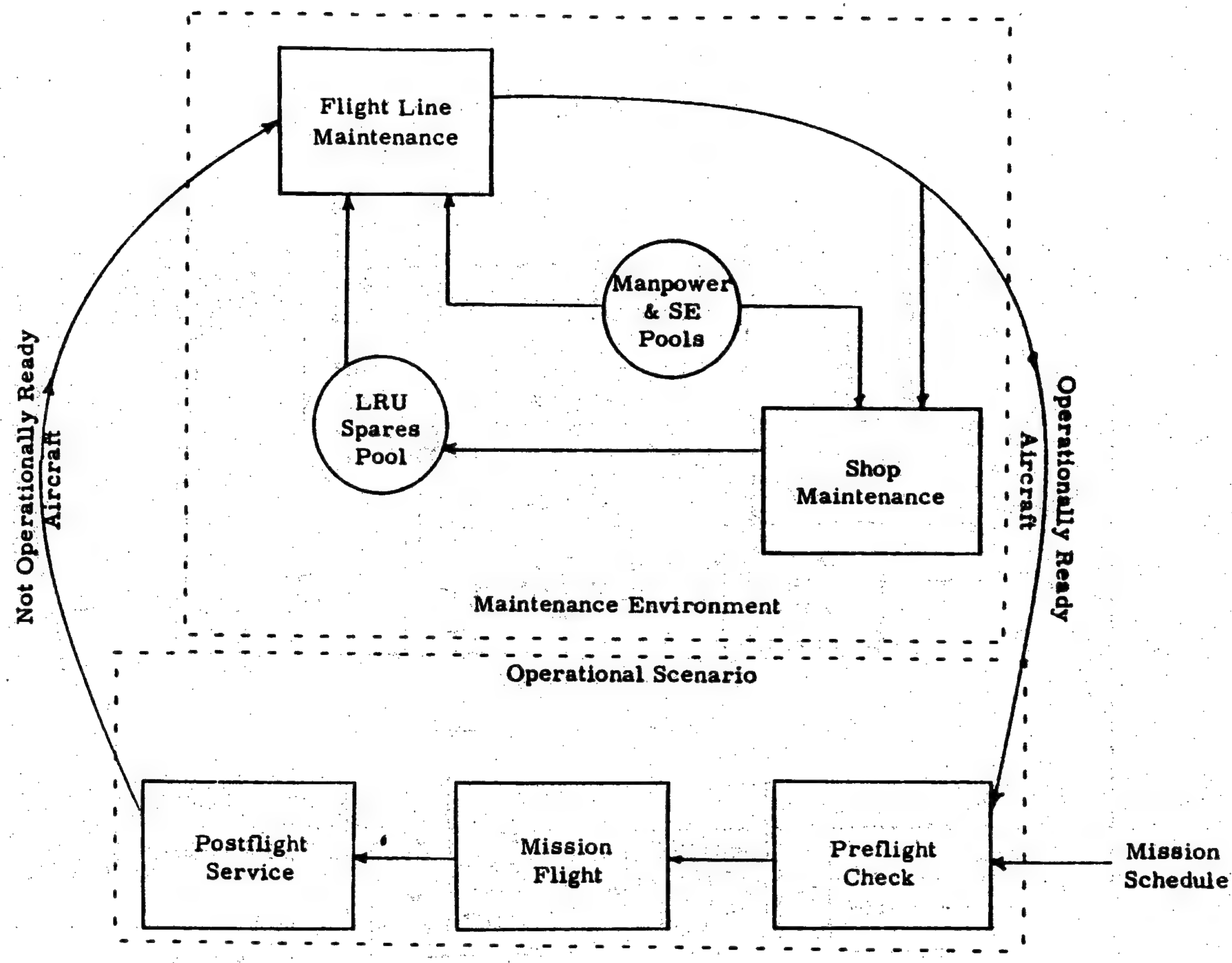


Figure 6 R&M OPERATIONS AND MAINTENANCE PROCESS

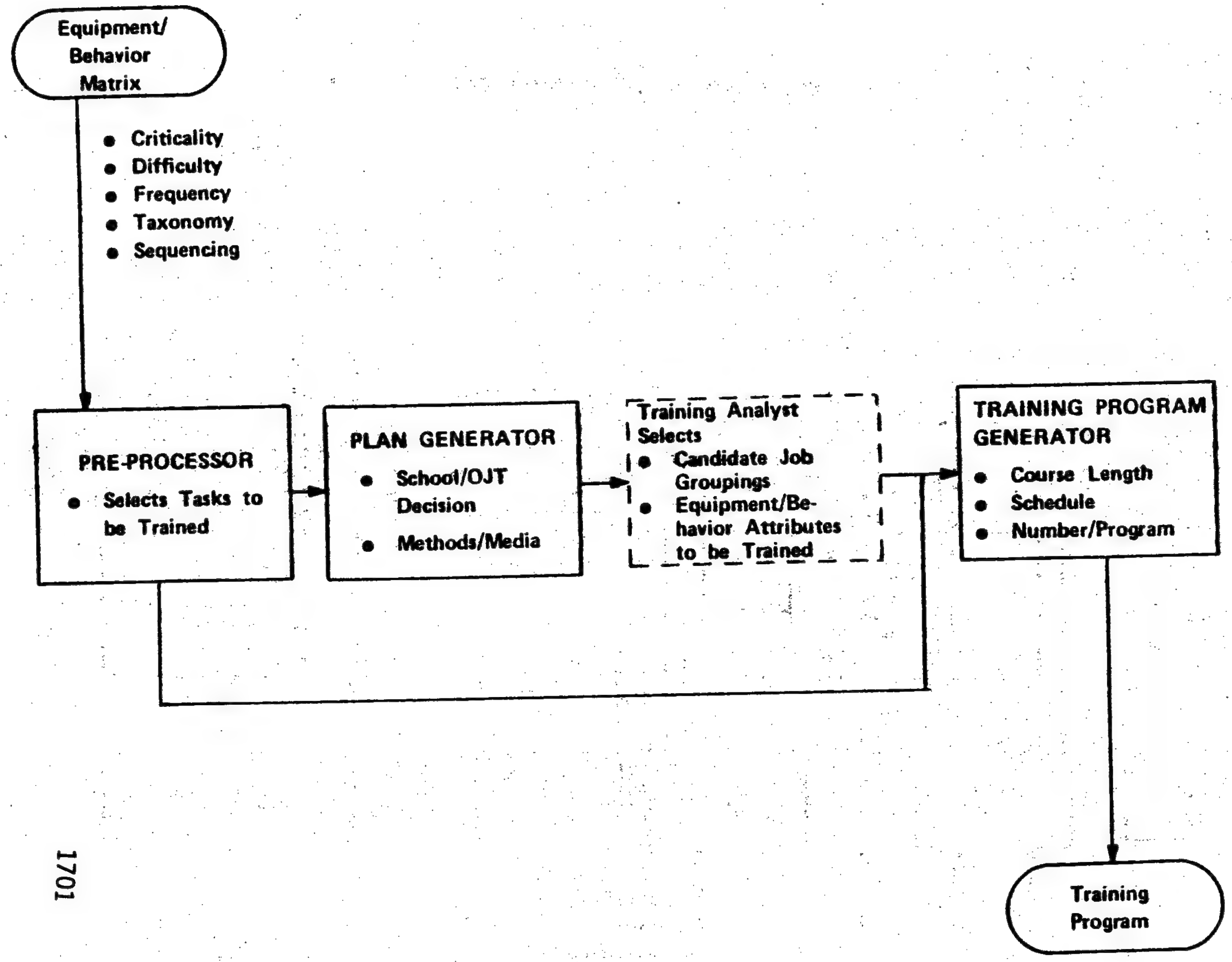


Figure 7 BASIC TRAINING MODEL CONCEPT

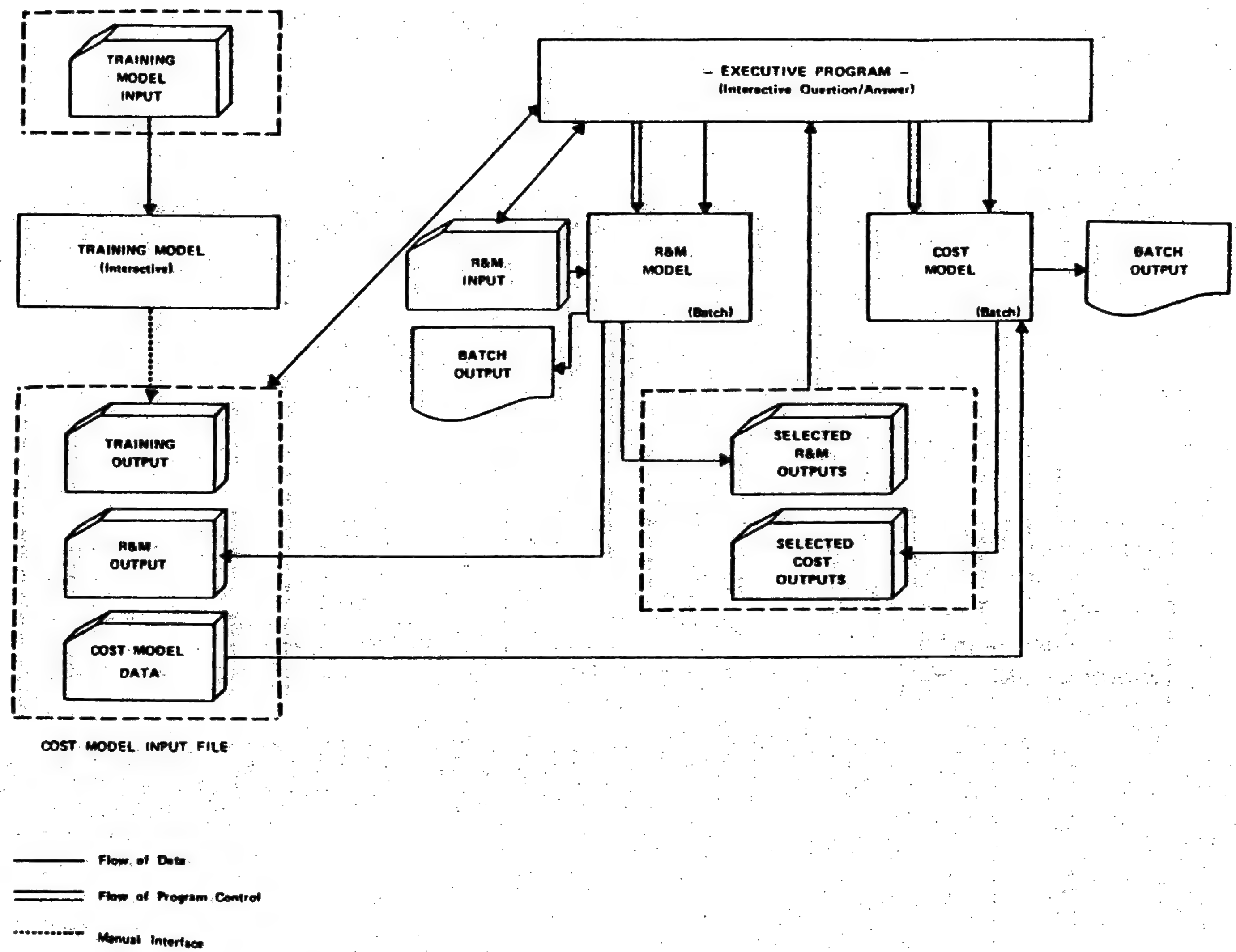


Figure 8 OVERVIEW OF LCCIM OPERATION

PACTS: USE OF INDIVIDUALIZED AUTOMATED TRAINING TECHNOLOGY

BY

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PACTS: Use of Individualized Automated Training Technology

Abstract

The cost effectiveness of Individualized Automated Training (IAT) is readily seen in reduced instructor requirements, increased training standardization, increased trainee proficiency, and increased trainee throughput. The PACTS program which combines computer speech recognition, computer speech synthesis, automated performance measurement, automated syllabus control, and instructor modeling is one example of successful IAT in the laboratory. PACTS technology has advanced to 6.4 for field evaluation at the Navy's Air Traffic Control School and the Fleet Combat Training Center, Pacific.

PACTS provides automated subsystems to introduce the trainee to his task by combining voice technology with hands-on practice. Following a run, voice technology is combined with models of the instructor to provide automated critique of trainee performance. Thus, PACTS frees the instructor of routine tasks, while at the same time increasing training standardization.

Introduction

Individualized automated training has a number of advantages over more traditional approaches to training. Automation of training relieves the instructor of busywork chores such as equipment setup and bookkeeping. He is thus free to use his time counseling students in his role as training manager. Individualized instruction, with its self-paced nature maintains the motivation of the trainee. Objective scoring is potentially more consistent than subjective ratings. Uniformity can be maintained in the proficiency level of the end product, the trainee. But, tasks requiring verbal commands have thus far been unamenable to individualized automated training techniques. Traditionally, performance measurement of verbal commands has required subjective ratings. This has effectively eliminated the potential development of individualized, automated self-paced curricula for the training of the Landing Signal Officer (LSO), the Air Intercept Controller (AIC), the Precision Approach Radar (PAR) Controller, and others. Computer recognition of human speech offers an alternative to subjective performance measurement by providing a basis of objectively evaluating verbal commands. The current state of the art has allowed such applications as automated baggage handling at Chicago's O'Hare airport. A more sophisticated recognition system is required for training, however. To that end, the Naval Training Equipment Center, Human Factors Laboratory Prototype Automated Controller Training System (PACTS) program will provide two separate experimental systems, one for PAR and one for AIC.

PACTS Training Requirements

The PAR Application

The task of the PAR controller is to issue advisories to aircraft on the basis of information from a radar indicator containing both azimuth (course) and elevation (glidepath) capabilities. The aircraft target projected on the elevation portion of the indicator is mentally divided into sections by the controller. This is because the radio terminology (R/T) for glidepath is defined in terms of these sections. Thus, at any one point in time, one and only one advisory is correct. Conversely, each advisory means one thing and only one thing. This tightly defined R/T is perfect for application of objective performance measurement. The drawback, of course, is that performance is verbal and has thus far required subjective ratings. In addition, the time required for human judgement results in inefficient performance measurement. The instructor cannot catch all the mistakes when there are many of them.

The major behavioral objective of current PAR training is to develop the skill to observe the trend of a target and correctly anticipate the corrections needed to provide a safe approach. The standard R/T is designed to provide a medium to carry out this objective, and PAR training exposes the student to as many approaches as possible so that the trainee may develop a high level of fluency with his R/T.

The primary need to fulfill its objective is for PAR training to teach the skill of extrapolation. A controller must recognize as quickly as possible what the pilot's skill is. He must recognize what the wind is doing to the aircraft heading. Then he must integrate this with the type aircraft to determine what advisories to issue.

The AIC Application

The task of the AIC is somewhat more complex than that of the PAR controller. In fact, the AIC has a job of multiple tasks which are complex in terms of concepts and decision processes, as well as response sequences. There are multiple aircraft to be monitored, and some of them may not be friendly. Complicated geometry must be used in the set-up of an intercept so that the enemy will not get the tactical advantage. A multitude of information such as heading, speed, altitude, and fuel state, as well as much more, can be monitored if the AIC pushes the correct button on the computerized console.

There are three basic behavioral objectives of current AIC training, and numerous supporting objectives. A trainee must be capable of learning to locate a specific aircraft in the midst of ground clutter, clouds, and other aircraft symbols, build a symbol for that aircraft, then perform the appropriate actions to cause the engagement of the aircraft from the computerized radar console. After that, the AIC must verify the position updating of the computer controlled symbol for all the targets on the console and establish a rhythm for all AIC actions. A trainee must also be capable of learning to recognize changes in the enemy target parameters such as altitude, airspeed or heading, then notify the pilot of the interceptors. In addition, unknown aircraft may enter the area in such a way as to create a potential conflict with the intercept, and the pilot must be kept informed of the actions of these. Finally, a trainee must be capable of learning to provide changes in heading to aircraft which are practicing. Often, the AIC is called upon to monitor pilots who want to practice intercepts, taking turns being the enemy for one another. In this situation, the AIC must contain the aircraft

within the geographic practice area as well as issue heading changes to set up the intercept for both aircraft.

Advanced Technology

The major behavioral objectives, then, can more efficiently be achieved through the application of computer speech recognition technology, and thereby the application of advanced training technologies. This is because with objective assessment of what the controller is saying, objective performance measurement is possible, and thus we have the capability of individualized instruction. The use of simulated environmental conditions allows the development of a syllabus of graduated conceptual complexity. The integration of these components results in an automated self-paced, individualized training system.

The job of the instructor now becomes one of training manager. His experience and skill may be exploited to its fullest. The training system can provide support in introducing the student to the R/T. The instructor can scan the progress of each student, then provide counseling to those who need it. Routine error feedback is provided by the training system. Only the instructor can provide human to human counseling for specific needs, and the training system provides more time for this valuable counseling.

Training System

Three major constraints are imposed by this system. Each user must pre-train the phrases. Recognition does not take place for random, individual words, only for predefined phrases. Each phrase is repeated a number of times and a Reference Array is formed representing the "average" way this speaker voices this particular phrase. Thus, the second constraint is that there must be a small number of phrases (about 50) which are to be recognized. If performance is to be evaluated based upon proper R/T, each phrase must be defined. The third constraint, due to performance measurement requirements, is that there be no ambiguous phrases -- right or wrong depending strictly on who the instructor is. Technically, the PACTS application appears to be conformable to these constraints.

To achieve high fidelity, simulation makes use of various models: The model of the controller is at the focal point of all other models, and serves to provide criteria to

the performance measurement system. A model of the aircraft and pilot allows for variation in the complexity of situations presented the student. The principle being used here is that exposure of the student to certain typical situations will allow him to generalize this experience to real world situations. The pilot model allows for systematic presentation of various skill levels of pilots. In addition, the equations used in modeling the pilot and aircraft responses also allow for introduction of various wind components. The adaptive variables of pilot skill, aircraft characteristics, and wind components are combined systematically to produce a syllabus graduated in problem complexity. As the skill of the trainee increases, he is allowed to attempt more complex problems.

Since the score is determined by the performance measurement system, the heart of scoring is the model controller. As it often happens, what constitutes "the" model controller is a matter of some discussion among instructors. Thus for automated training applications, one must determine the concepts which are definable, such as how to compute a turn, and leave other concepts to be developed by the instructor-student apprentice relationship.

Benefits

Results of laboratory efforts indicate that training can be enhanced and manpower costs reduced by a careful integration of advanced training technology with off-the-shelf computer speech recognition hardware which is enhanced with software algorithms designed for a specific vocabulary set.

The advantage brought to training by this technology is the capability to objectively measure speech behavior. Traditional training techniques for jobs which are primarily speech in nature require someone who can listen to what is being said. Otherwise, no direct measure of the speech behavior is possible. In addition to the requirement of having an instructor listen to the speech behavior, training often requires another person to cause changes in the environment which corresponds to the trainee's commands. For the PACTS tasks, this takes the form of "pseudo" pilots who "fly" a simulated aircraft target. This 2:1 ratio of support personnel to trainee results in a relatively high training cost.

Previous studies have demonstrated that in analogous situations, it has been possible to achieve savings of manpower and training time while gaining a uniform, high-quality

student output by introducing individualized automated instruction. This advanced technology would bring in its standard benefits such as objective performance measurement and complete individualized instruction. Moreover a fully automated system could provide greater realism in the performance of "aircraft" under control of students by accessing directly the computer model of aircraft dynamics rather than relying on the undetermined skills of a variety of pseudo-pilots. Additionally, the rapid processing of an automated system would make possible extrinsic feedback of task performance to the trainee in real-time.

Biographical Sketch

Dr. Robert Breaux received his Ph.D. in experimental psychology from Texas Tech University in 1974. He is a Research Psychologist in the Human Factors Laboratory at the Naval Training Equipment Center. He has an interest in application of the theoretical advances from the psychological laboratory to the classroom situation. Publications and papers include computer application for statistics, basic learning research, concept learning math models, and learning strategies. He is an instrument rated commercial pilot, and a certified flight instructor.

INCREASING THE AFFORDABILITY OF I-LEVEL MAINTENANCE TRAINING THROUGH SIMULATION

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Increasing the Affordability of I-Level Maintenance Training Through Application of Simulation

Abstract

Current concepts for Air Force Technical Training in the maintenance of today's sophisticated weapon systems rely heavily on the use of operational equipment. This is especially so for training in use and repair of the Automatic Test Equipment (ATE) associated with the Intermediate Level (I-Level) repair of aircraft avionics systems and their "black-box" components. A number of problems associated with the use of ATE for training, including (1) cost, (2) complexity, (3) low reliability when used in the classroom, (4) inability to demonstrate realistic malfunctions, have aroused the Air Force into seeking alternatives to the use of operational equipment for training.

In the case of ATE, the primary alternative currently being considered is computer-based simulation of the operational equipment. The Air Force Human Resources Laboratory, Technical Training Division, under contract with the Honeywell Corporation, began in August 1976 to develop a simulator for one item of ATE from the F-111D weapon system. The 6883 Test Station, known as the F-111D Converter/Flight Controls Test Station, was selected for this simulation research effort based on a requirement from the Air Force's Air Training Command (ATC) which was concerned with providing adequate "hands-on" training for I-Level repair activities.

The 6883 Simulator System design which was based on a detailed system specification developed earlier, is a multi-computer system which drives simulations of the 6883 Test Station and associated F-111D avionics components, using appropriate hardware interfaces. Student actions on the simulated equipment are sensed by the computer through the same interfaces. Guidance and feedback are provided to students via a CRT/keyboard and random access slide projector. Student performance will be recorded by the computer system and output to the instructor's CRT/keyboard in a summarized format.

Simulation features incorporated into the 6883 Simulator System include metal photos, both with and without functional controls/displays, and simulated printed circuit (PC) cards, using epoxy molding and color photography.

Research questions which will be addressed in this program are many and varied. Previous research in the area of maintenance simulation has been limited in scope and has provided very few conclusive answers to many nagging questions. Although many studies (reviewed in the paper) have emphasized the potential of simulation in maintenance training, the fact remains that no satisfactory methodology for incorporating simulation into maintenance training systems acquisition has been developed. Furthermore, there are a host of unresolved issues which must be addressed and for which guidelines must be developed prior to optimization of simulator use for Air Force technical training. This paper describes the variuos issues and AFHRL's approach to resolving these issues using the 6883 simulator as a test bed.

Introduction

Teaching students how to operate and maintain sophisticated electronic equipment has always been a problem in Air Force technical training. Over the years, various approaches have been used including mock-ups, cutaways, and bench mounted actual aircraft parts. Although varying levels of success have been achieved with the above approaches, problems such as high cost, lack of reliability, inability to insert controlled malfunctions, and an absence of instructional features have all contributed to the demand for more cost-and-training effective approaches.

With the advent of mini and micro computer technology and software modularization, it has now become possible to simulate the man/machine interactions of even the most sophisticated maintenance equipment at a fraction of the cost of the actual equipment. In addition, the decreasing costs of peripherals have made it possible to incorporate instructional features into maintenance training simulators that tend to dwarf the instructional capabilities of the "real" equipment.

Although the age of simulation technology has arrived, the know-how required to effectively utilize these new developments has been lagging. A research program is now underway at the Technical Training Division of the Air Force Human Resources Laboratory to provide the missing "know-how." This project, which is called Project 2361, "Simulation for Maintenance Training," was designed to develop simulation technology for maintenance training by providing comprehensive demonstrations of simulation technology in a variety of applications. Lessons learned will be incorporated into detailed "how to" guides and specifications.

The main thrust of this paper is to discuss the recent development of a maintenance training simulator that will be used by AFHRL as a research test bed for resolving some of the major issues which must be addressed prior to the optimal use of simulation in Air Force technical training.

Development of the 6883 Maintenance Training System

The primary objectives of this project were to a) design, fabricate, and test a simulator for the 6883 Converter/Flight Controls Test Station;

b) establish a research test bed for investigating the major variables that impact the design of training equipment for intermediate-level maintenance (I-level, or "shop" maintenance); and c) evaluate the effectiveness of simulation technology for training Air Force technicians for a wide variety of checkout and troubleshooting procedures involved in the operation and maintenance of the 6883 Converter/Flight Controls Test Station depicted in Figure 1.

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Insert Figure 1 about here

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The 6883 Converter/Flight Controls Test Station is part of the aerospace ground equipment comprising the F-111D avionics I-level maintenance shop. Two courses related to I-level maintenance of F-111D avionics are taught at Lowry Technical Training Center (LTTC), Lowry Air Force Base, Colorado. Course 3ABR32631D-002 trains individuals to operate the various test stations in the F-111D shop, including the 6883, and to test, inspect, troubleshoot, and repair faulty line replaceable units (LRUs) from the aircraft. Trainees also learn to perform limited tests of the test station to ensure that it is functioning properly. Course 3ABR32630B-000/001/002 trains individuals to perform detailed tests; to inspect, troubleshoot, and repair malfunctioning test stations; and to perform periodic preventative maintenance on the test stations.

Current Approach to I-Level Training

Currently, I-level maintenance training is conducted on actual equipment. This approach has obvious value in that procurement is easily accomplished (no special training equipment design is required) and the realism provided has significant motivational value for both instructors and students. However, several major problems have arisen that limit the training value of actual equipment which generally is not designed to be used in a training environment. One primary disadvantage of using actual equipment for I-level training is the cost of acquisition and maintenance. Acquisition costs of such hardware often exceed several million dollars. Another disadvantage of using actual equipment comes from the nature of most I-level jobs: In order to train a student to become familiar with a specific procedure, the actual equipment must be run through highly procedural, time consuming exercises that require little operator participation.

Other shortcomings of the actual equipment approach to training are:

Extremely low reliability of the actual 6883 test station, resulting in low availability of the device for training purposes,

High risk of severe injury to trainees,

High risk of costly, student-induced damage to the equipment,

Limited range of equipment faults and emergency conditions to which trainees can be exposed, and

Feedback delivery which necessitates instructor's continued presence.

These problems limit hands-on procedures training and troubleshooting practice. The 6883 Maintenance Training System (MTS) was designed to alleviate the above problems by providing a much less costly, and more forgiving, training environment that emphasizes job tasks requiring manual assistance and troubleshooting knowledge.

Design Approach

The design of the 6883 MTS was based on a job task analysis conducted by AFHRL/TT with the assistance of ATC instructors who were familiar with the operation and maintenance of the 6883 test station. This task analysis was subsequently incorporated into an AFHRL/TT developed functional specification for the 6883 MTS (Miller and Gardner, 1975). A detailed description of the task analysis and methodology for developing the functional specification is contained in that report. The above functional specification was used as the primary contractual document for the work described in this paper.

The general approach adopted for the development of the 6883 MTS included: a) formation of a multidisciplinary team, including training specialists, engineers, human factors psychologists, and system programmers; b) Extensive involvement of Air Force instructors and subject matter experts; c) Refinement, through a "front-end" analysis, of the functional specification for use in engineering design; d) incorporation of distributed processing architecture for expansion capability; and e) Use of modular software to maximize general application.

This approach was organized around a six-element system concept; 1) simulated hardware, 2) student console, 3) instructor console, 4) computer hardware, 5) system software, and 6) instructional features. The selected approach emphasized use of proven, off-the-shelf hardware and software elements wherever possible, development of cost-effective simulation techniques, and development of modular software to promote flexibility. Figure 2 is an artist's concept of the simulation system prior to fabrication.

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Insert Figure 2 about here

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System Description

This section provides a description of the basic 6883 MTS and a discussion of the major design features. A detailed discussion will be provided in a soon to be published AFHRL Technical Report entitled, "6883 Converter/Flight Controls Test Station Maintenance Training System."

Configuration

The 6883 MTS is a dual-computer system which drives simulations of the 6883 test station and associated LRUs through appropriate interface hardware. The 6883 MTS, shown in Figure 3, incorporates a

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Insert Figure 3 about here

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simulated 6883 test station (6883 simulator), three simulated LRUs, and simulations of four associated interface adapters. Student actions on the simulated equipment are sensed by the computer through the same interfaces. Appropriate student guidance and feedback are provided by a CRT/keyboard and random access slide projector. Student performance is recorded by the computer system and is output to the instructor's CRT/keyboard in summarized form. These same performance data can be output to a cassette tape and line printer for record-keeping. A training system hardware block diagram is shown in Figure 4.

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Insert Figure 4 about here

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More specifically, the 6883 MTS computer system architecture is a multi-processor, distributed system providing expansion capabilities. One Honeywell-716 computer (H716) functions as a classroom controller, operating the instructor station CRT/keyboard, high-speed printer, disk, tape drives, and interprocessor interface.

Data transfer between the classroom controller and the student station controller is performed using an industry standard RS232 interface. Three (or more) additional RS232 interfaces can be used to connect additional test station simulators to the classroom controller. The 6883 system computer architecture is therefore designed to permit expansion to a total of four or more simulated test stations. In this manner, a single instructor at the console could simultaneously monitor several different station simulators.

The second H716 functions as the student station controller. The student station controller operates the student CRT/keyboard, random access display unit, interprocessor interface, I/O multiplexer and test station, and LRU simulated hardware. A trainer interface electronics system (TIES) provides an input/output multiplexing capability for sensing student actions and for driving displays and indicators on the simulated equipment. A random-access MAST slide projector is computer-controlled through this multiplexer.

System Elements

The 6883 MTS depicted in Figure 3 was installed at Lowry AFB in June 1978. Major elements are the a) instructor station, b) student station and c) test simulator hardware.

Instructor station. The instructor station consists of a classroom controller and an instructor console as shown in Figure 5. The heart of the classroom controller is a standard, commercially available H716 minicomputer with 32,768 words of internal memory.

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Insert Figure 5 about here

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Other off-the-shelf equipment used within the classroom controller are a Honeywell 9030 expansion drawer, a Honeywell 5400 cassette magnetic tape with the 5401 expansion feature (two cassette tape operation), a Honeywell 4768 dual cartridge disk, and a Honeywell 9400 power distribution unit.

The instructor console consists of a Hewlett-Packard Model (HP) 2640B interactive display terminal (CRT), a Centronics Model 102AL line printer, and a desk and chair.

Student station. In the 6883 MTS, the student station, shown in Figure 6, is the center of training activities. The student

Insert Figure 6 about here

station elements--student station controller, the student console (CRT/keyboard and slide projector), the simulated 6883 test station, and simulated 6883 test station, and simulated LRUs--interact to provide the student with computer-generated responses which mimic operational equipment analog (meters) and discrete (lamp and digital panel meter) signal responses. Messages displayed on the interactive CRT terminal supplement simulated operational equipment responses and guide the student through the correct interpretation of technical material. Figure 6 shows the student station controller, interactive display terminal, and slide projection system.

Simulation hardware. The 6883 simulated hardware consists of:

6883 test station

Three LRUs
- Feel and Trim Assembly
- Multiplexer converter set
- Flight control yaw computer

Four adapters
- Three station/LRU interfaces
- One station self-test

Insert Figure 7 about here

All cabling and hoses

The 6883 test station simulation shown in Figure 7 consists of 28 metal photo panels, three pull-out drawers, and an unmodified GFE oscilloscope mounted in four salvage GFE equipment racks. These racks are mounted on fork lift support bases, two racks per base. The level of simulation for each panel varies. Certain panels are complete visual simulation, while others contain many functionally simulated components. Figure 8 provides a panel-by-panel breakdown of the level of simulation fidelity on the test station. Three of

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Insert Figure 8 about here

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the drawers (DATAC, power supply, and flight control sensor) are simulated as pull-out drawers. Hands-on tasks such as removal and replacement of cards, power supply adjustments, changing relays, resetting circuit breakers, and adjustment of potentiometers are fully simulated in the three pull-out drawers. Students actually make the required hands-on adjustments which are interactively sensed and displayed via the simulated digital voltmeter or oscilloscope. In this manner, complex hands-on maintenance activities required of 6883 technicians are simulated with a high degree of realism.

LRU simulations. In general, the exterior of each of the three LRUs is simulated in appearance, using an appropriate GFE-salvaged LRU chassis as the basis for fabrication. These chassis, stripped of operational equipment, and the corresponding covers are painted to match the test station simulator. The front panels are represented using metal photos, reflecting identification plates, elapsed time meters, and jack and switch identifiers. The necessary functional features of each unit are mounted at the appropriate positions on the metal photos. The functional features of specific LRUs are detailed in the following paragraphs. Each simulated LRU is appropriately weighted to resemble the corresponding actual equipment. All simulated LRUs have handles in the appropriate locations. As an example, the interior of the feel and trim assembly LRU (Figure 9) is simulated through a combination of metal photos and metal sculpture. Push buttons are mounted on selected components in the photos and on selected

sculpted components as well. These buttons are used by the trainee to indicate the location of components that are identified as fault sources during malfunction lessons.

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Insert Figure 9 about here

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Training System Software

In addition to standard operating system software, the 6883 MTS includes trainer common modules and 6883-specific modules which provide flexibility to meet changing system requirements.

Trainer common modules. The trainer common modules are the building block subprograms that would be common to many types of trainers. They have been designed to be inserted into a variety of trainer applications, both low fidelity and high fidelity as required. These modules include the following: a) training system controller, b) student procedure monitor, c) instructor monitor, d) student test routines, digital voltmeter and oscilloscope simulations, and self-test diagnostics.

6883-specific modules. The 6883-specific modules are the building block subprograms that apply primarily to the current 6883 trainer and to its unique training requirements. The building block approach has been used here to allow easy modification, resulting from changes in trainer requirements. The approach allows the same outline to be used for lesson material for other types of trainers.

Instructional Features

In this portion of the paper, the major instructional design philosophy will be discussed along with a review of the courseware structure, student performance measures, and student and instructor feedback.

Instructional design philosophy. The interactive training philosophy of the 6883 system is depicted in Figure 10. The instructional design of the 6883 MTS emphasizes not only realistic simulation of the

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Insert Figure 10 about here

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actual 6883 system, but also extensive feedback, monitoring, cueing, and guidance of trainee actions on the 6883 MTS. Here the computer replaces the instructor as the master overseer of the system. The computer checks the accuracy of all student inputs, determines that technical orders are being followed as specified in the instructional programs, and provides appropriate guidance and feedback in the event of an error. The system enables the trainee to conveniently repeat a sequence, compress time, and stop the program if so desired.

As depicted in Figure 10, the student has a direct link to the 6883 MTS. In a typical training situation which utilizes actual equipment, the student is required to check with the instructor prior to most system inputs. In the simulator training environment, the instructor does not have to "hold the student by the hand," enabling the student to work at his own pace. Errors made by a student are recorded, but can easily be corrected without fear of injury to the student or damage to the equipment. Although the instructor still plays an active role in simulator training, the computer based system frees up the instructor to concentrate on the remainder of the class which is waiting to use the simulator. Thus, the instructor's monitoring and intervention requirements are dramtatically less, but his control over the training environment is far greater than in the conventional situation. The instructor using the 6883 MTS can choose from 58 lessons of which 17 are LRU malfunction lessons and 34 are test station malfunctions. The remaining 7 lessons are for normal procedures.

<u>Courseware function and structure</u>. Courseware may be defined as the computer-directed presentation of instructional material via a combination of media. The courseware program controls the interaction between the software and the simulation hardware and between both of these and the trainee. The instructional material includes the text messages presented via the CRT and the graphics presented via slides. Courseware is essentially a set of computer programs written in a mnemonic language designed for the 6883 application. The text messages called for by the program are written in natural English. Because the 6883 system is a procedures trainer, the courseware completely specifies the sequence of actions expected of the trainee and the information that the trainee receives via the CRT, slide projector, and the test station displays. The courseware provides for prompting and feedback where necessary. For example, because every trainee action is monitored, any incorrect switch or

control setting can immediately be called to the trainee's attention. Since the structure of courseware is modular and hierarchical, lessons can be easily modified or rearranged.

Student performance measures. The 6883 system is designed as a closed-loop device. The actions and responses of trainees are continually monitored. The courseware calls out the expected action or answer at each point necessary and if the correct response fails to occur, an error branch is invoked. The system accumulates six error types and two auxiliary measures:

Critical or safety error

Fault detect error

Procedural error

Keyboard (CRT) error

Component location error

Switch/control setting configuration error

System helps

Student helps

Simulator status panel. The simulator status panel located in Bay 3 of the simulated test station is a trainer-unique panel that provides information about the state of the simulator at any given time. This panel is not found on the actual 6883 test station; it is present for training purposes only. The panel contains a number of push buttons and indicators designed to aid in performing the lessons. Figure 11 shows this special purpose panel.

- - - - - - - - - - - - - - - - - -

Insert Figure 11 about here

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Instructor aids. When any type of error occurs, a status log is automatically displayed at the instructor station CRT. Figure 12 shows the format in which the performance information is presented. The instructor may obtain this display on demand from the system and may request a hard copy of the status log.

- - - - - - - - - - - - - - - - - -

Insert Figure 12 about here

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System Design Features

Hardware

The visual simulation required for panels and the three-dimensional simulation needed for printed circuit cards led to application of two technologies that saved considerable time and money in production.

Metal photos. A metal photo is a high-resolution photograph embedded in the surface of a metal plate. Photographs are taken of the actual equipment as the first step in the development of metal photos. Next, photographic half-tone negatives are produced and a photo-sensitive aluminum plate is then exposed to the negative in the same manner as in producing a standard black-and-white photographic print. The resultant high-resolution image (1000 lines/mm) is sealed under an anodized, clear, sapphire-hard surface that protects the image from scratching, fading, peeling, and chipping. Normal metal working processes such as bending, cutting, or installing components may be used on these panels. The metal photo panels thus provide the durability of an aluminum panel with the low-cost of a photograph. The use of this technology avoids the cost of the artwork and engraving associated with actual panel production.

Circuit cards. The simulated circuit cards were produced by laminating color photographs onto a rigid substrate, an aluminum alloy sheet for all cards except those in the FCS drawer. For the FCS cards a glass/epoxy substrate was used to electrically insulate their edge connectors. The color photographs are embedded in plastic which both attaches them to the substrate and provides a durable surface. The cards for the DATAC drawer have simulated transistor cans bonded

to their surface. The color photographs of the actual circuit cards provide a high degree of fidelity with low cost. Since actual circuit cards are quite expensive, this technique resulted in cost savings of 75 to 80 percent.

Software

The top-down, modular approach to software design proved to be the best method for achieving reliable and manageable programs for the training requirement. A top-down, modular approach using hierarchy plus input-processing-output reports allowed a more efficient use of programmer talent, provided visible levels of responsibility, yielded a definite software architecture easily checked for consistency (due to well-defined software interfaces), and aided the system integration and verification activities.

The top-down modular approach assured compliance with training requirements by a check-off method. That is, each computer program component was divided into functional portions and each module's output, function and input requirements were defined and validated. This close relationship between functional requirements and software module allowed rapid cross-checking by nonprogramming personnel. The use of an informal, structured program design language assisted the Air Force technical personnel in checking compliance with requirements.

Research Test Bed

In addition to designing and developing the 6883 MTS to demonstrate the feasibility of simulation technology in an operational training environment, AFHRL plans to use the 6883 MTS as a major test bed to collect baseline information and conduct research in several areas that should significantly impact future maintenance simulator procurements.

Research Issues

Probably the most important question to ask relative to the effectiveness of any training device is, "What is the transfer of training to the actual job situation?" While this question is of central importance, attempts to answer it in previous research have produced inconclusive results. AFHRL is currently attempting to answer this

question using a carefully designed study incorporating both qualitative and quantitative approaches to determine the training - and cost effectiveness of the 6883 MTS; included within this study will be a trainee, field follow-up to assess transfer of training.

Other research questions which will be addressed in the 6883 test bed environment include a) the level of fidelity (realism) required in maintenance simulators (this question has tremendous cost implications), b) the differential effectiveness of static versus dynamic display media, and c) modularity requirements in hardware and software. Research is currently underway to develop a two-dimensional simulation of the 6883 MTS. This device should cost approximately 50 percent of the 6883 MTS costs and will enable AFHRL to systematically investigate varying levels of fidelity in the 6883 environment and also compare different hardware and software simulation techniques. The above research, coupled with R&D in even less expensive techniques such as computer graphics and paper and pencil approaches, should provide the Air Force with answers to many of the R&D issues discussed above.

Coupling R&D with Operational Requirements.

Results of research described above, along with other R&D conducted in AFHRL Project 2361, "Simulation for Maintenance Training," will be incorporated into a comprehensive effort to provide the Air Force with new specifications, guides, handbooks, and revised Military Standards specifically tailored to the design and procurement of new technology maintenance simulators.

BIOGRAPHICAL SKETCH

Mr. Miller received his B.A. degree in Psychology from Duquesne University in 1966 and his M.S. degree from Missouri State University at Warrensburg in 1969. He joined the staff of the Technical Training Division of the Air Force Human Resources Laboratory in 1972 after serving a tour of duty in the Air Force as a Launch Control Officer and Missile Staff Training Officer in the Minuteman system. Mr. Miller is assigned to the Training Techniques and Evaluation section where he is involved in research on the design and evaluation of training simulators, devices, and aids; and the development and application of individualized and automated self-instruction techniques for technical training. Mr. Miller has authored over 20 technical reports and papers in the area of training systems, especially simulation technology as it applies to maintenance training. He received the Department of the Air Force Outstanding Civilian Performance Award in 1976. Mr. Miller is currently involved as a task scientist and program control officer in an advanced development project entitled, Simulation for Maintenance Training. Mr. Miller is nearing completion of his PhD in Educational Psychology at the University of Colorado.

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Miller, G.G., and Gardner, E.M. Advanced Simulator Performance Specification for an F-111 Test Station. AFHRL-TR-75-70, AD-025 853, Lowry AFB, Colo: Technical Training Division, Air Force Human Resources Laboratory, November 1975.

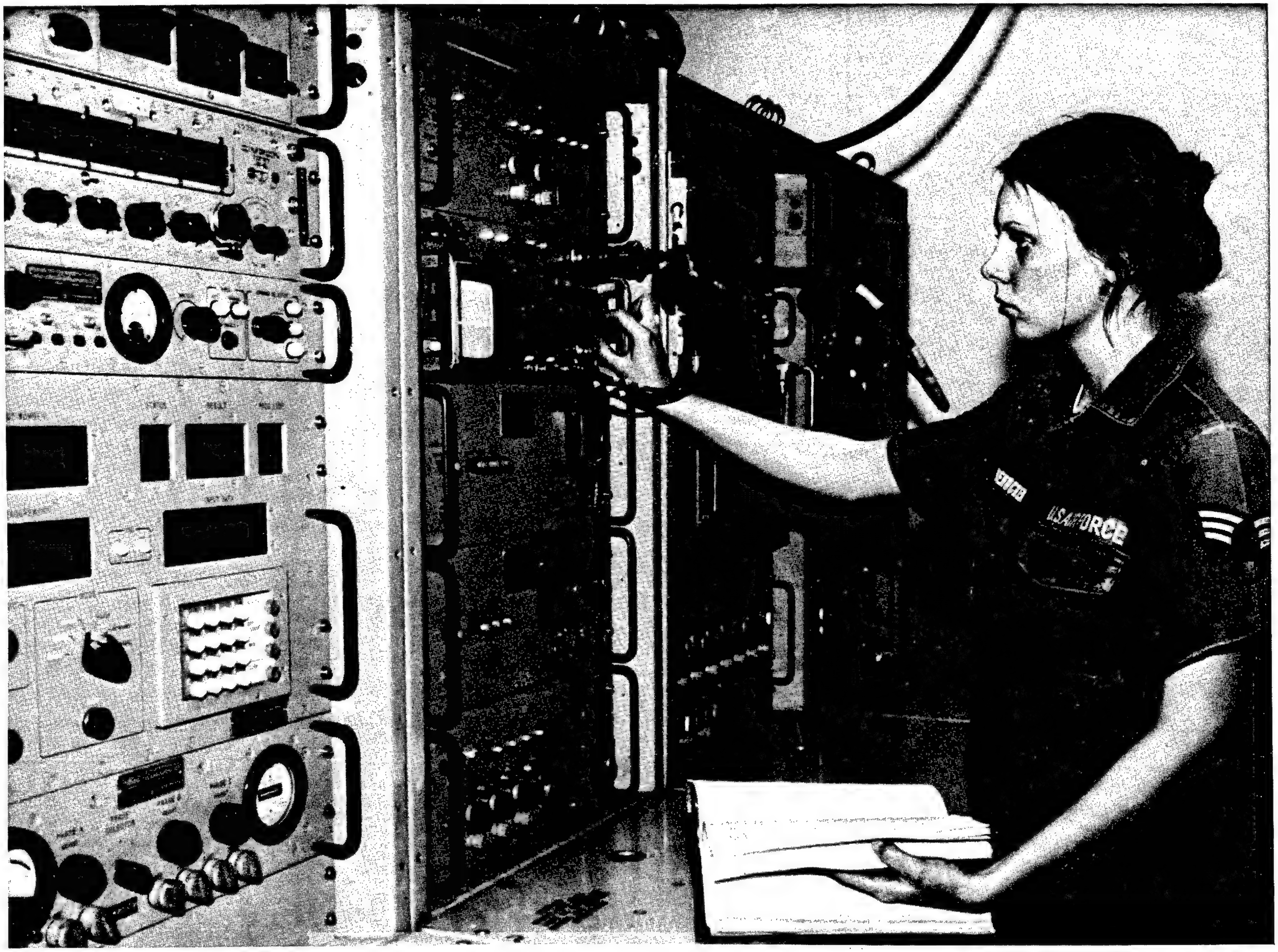

Figure 1. 6883 Converter/Flight Controls Test Station for F-111D 1729

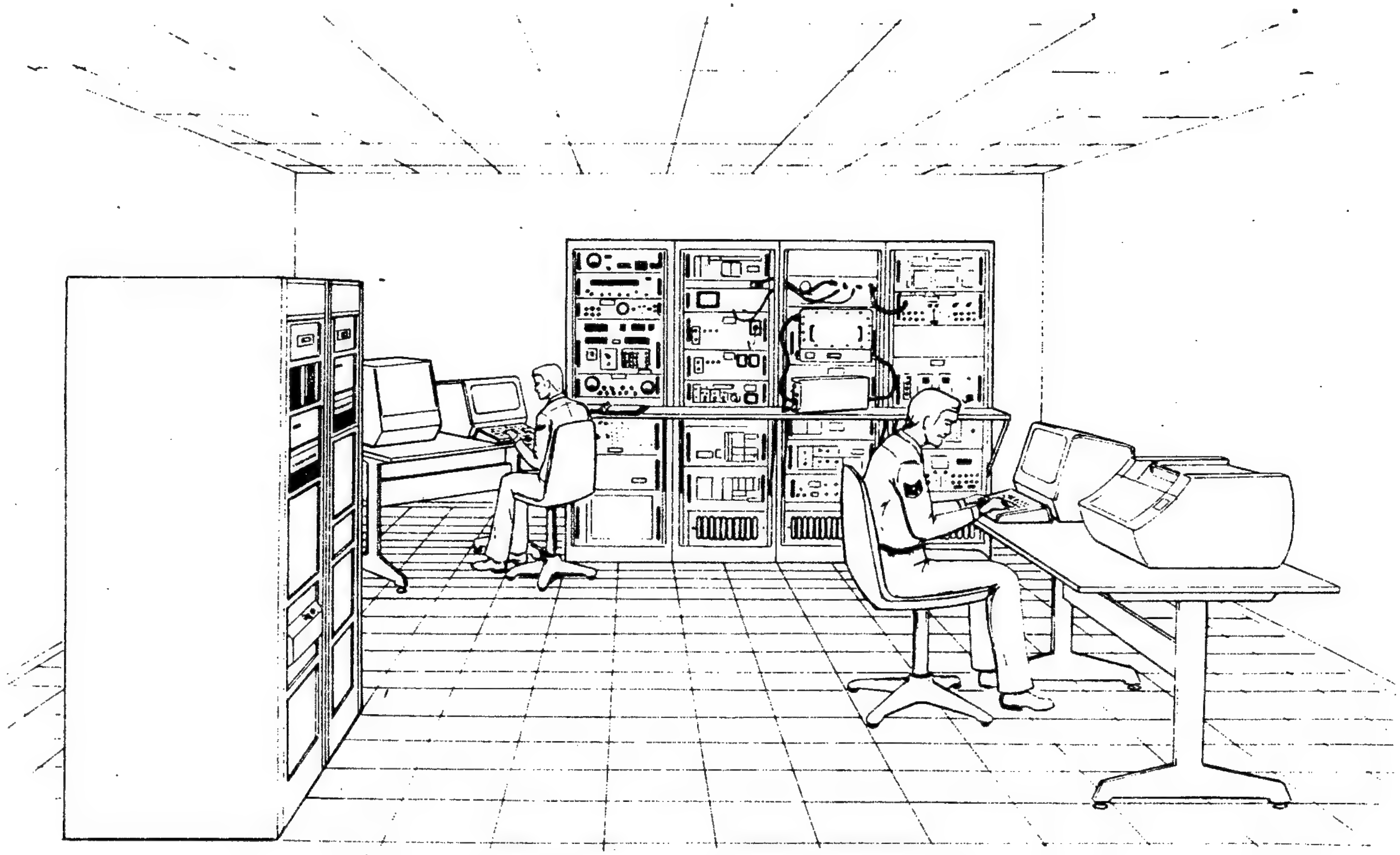

Figure 2. Artists Conceptualization of Classroom Arrangement of Hardware for 6883 Maintenance Training System

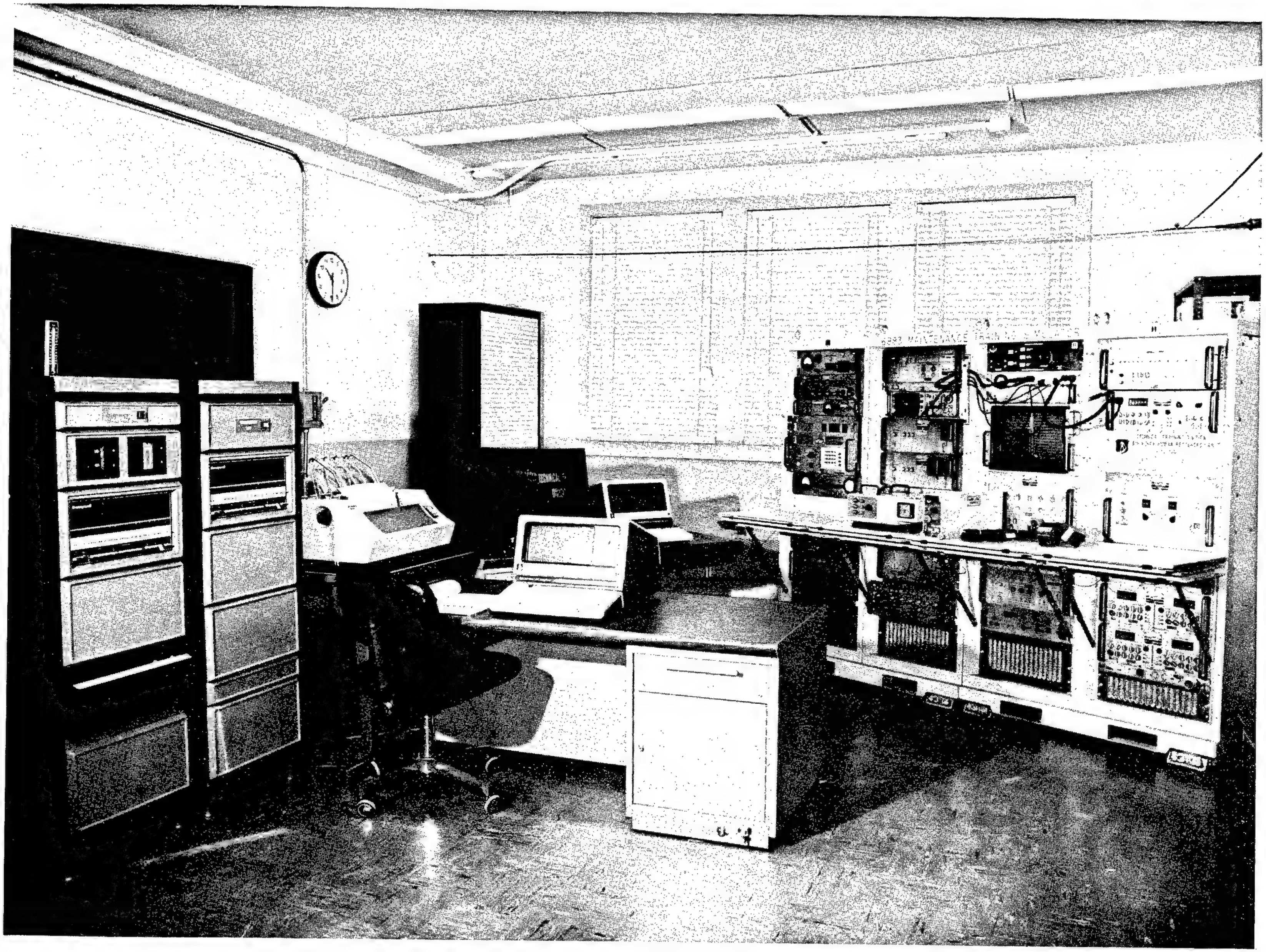

Figure 3. 6883 Maintenance Training System.

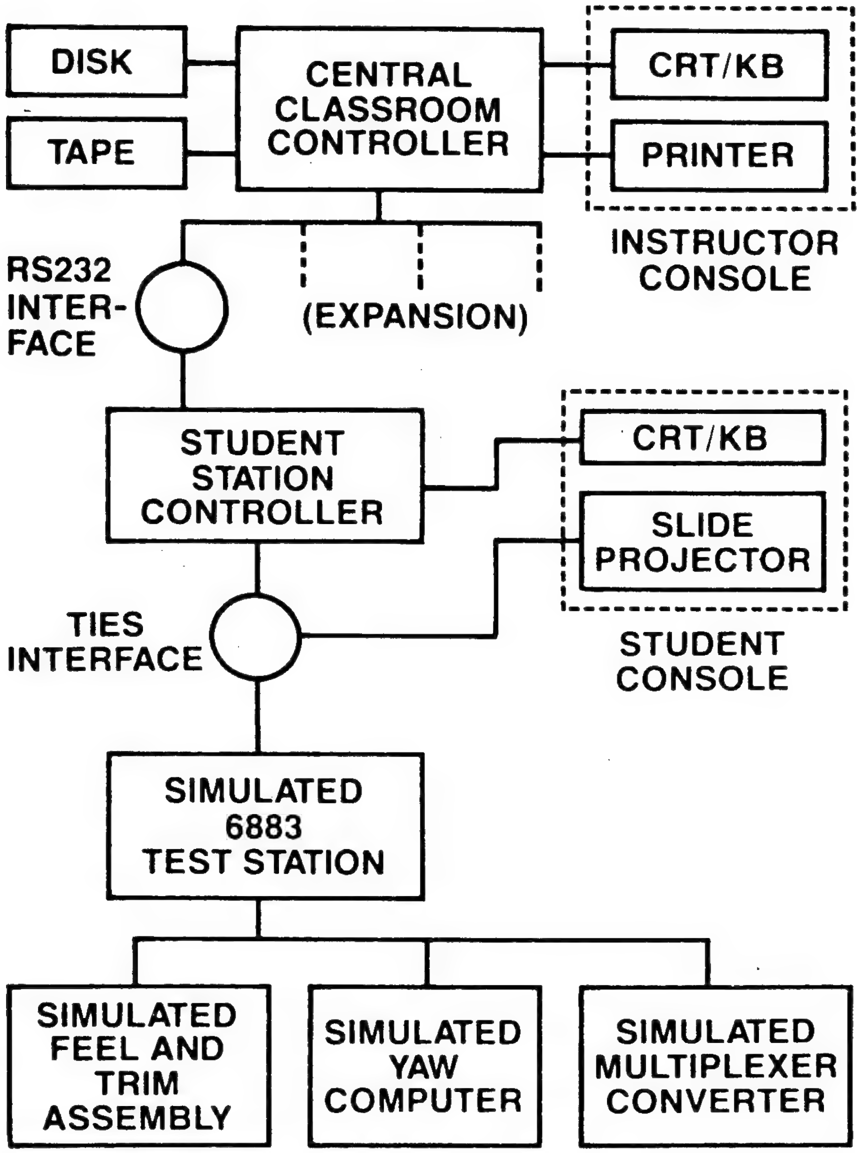

Figure 4. 6883 Maintenance Training System Hardware Block Diagram

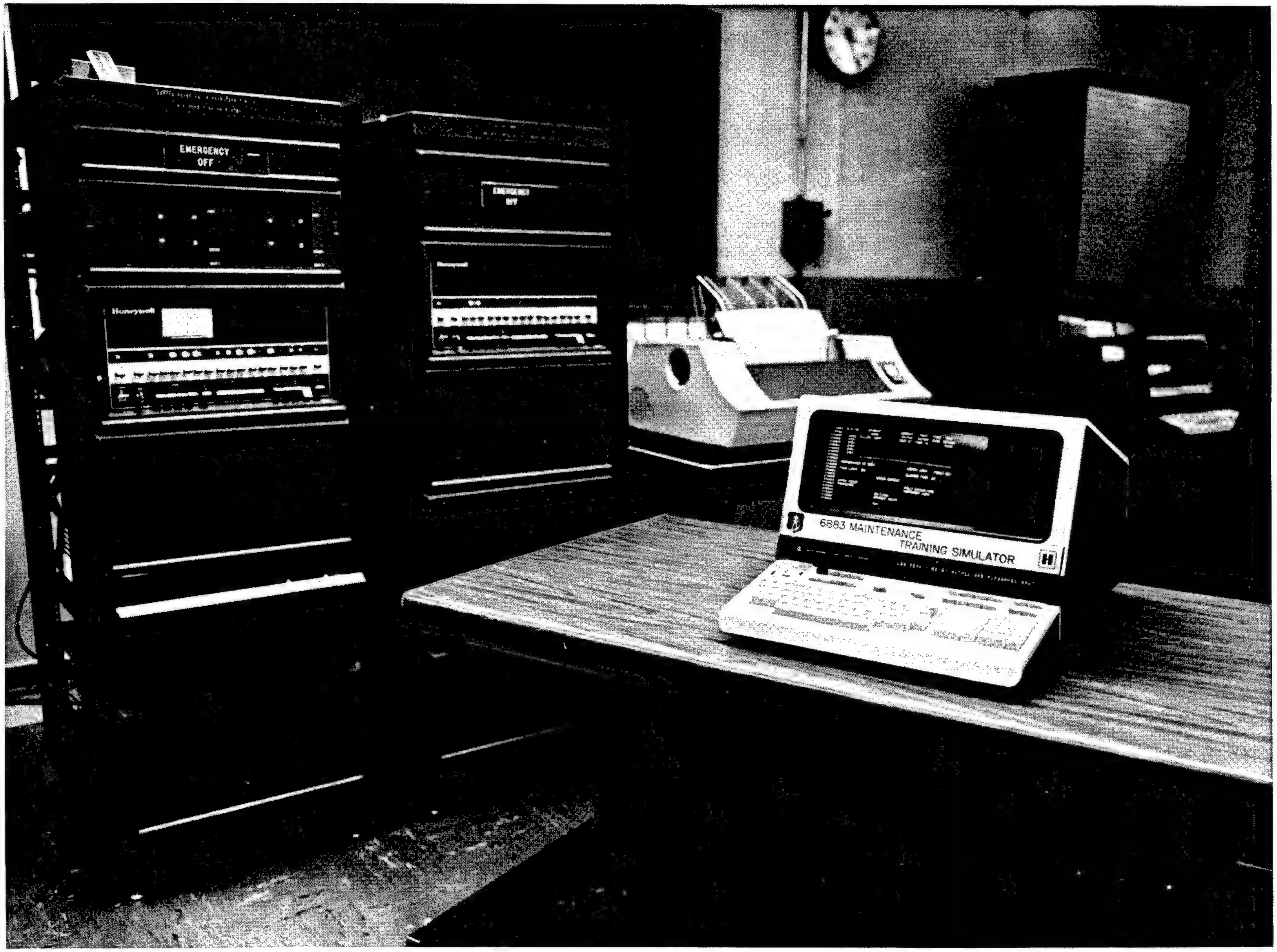

Figure 5. 6883 MTS Instructor Station.

Figure 6. 6883 MTS Student Station.

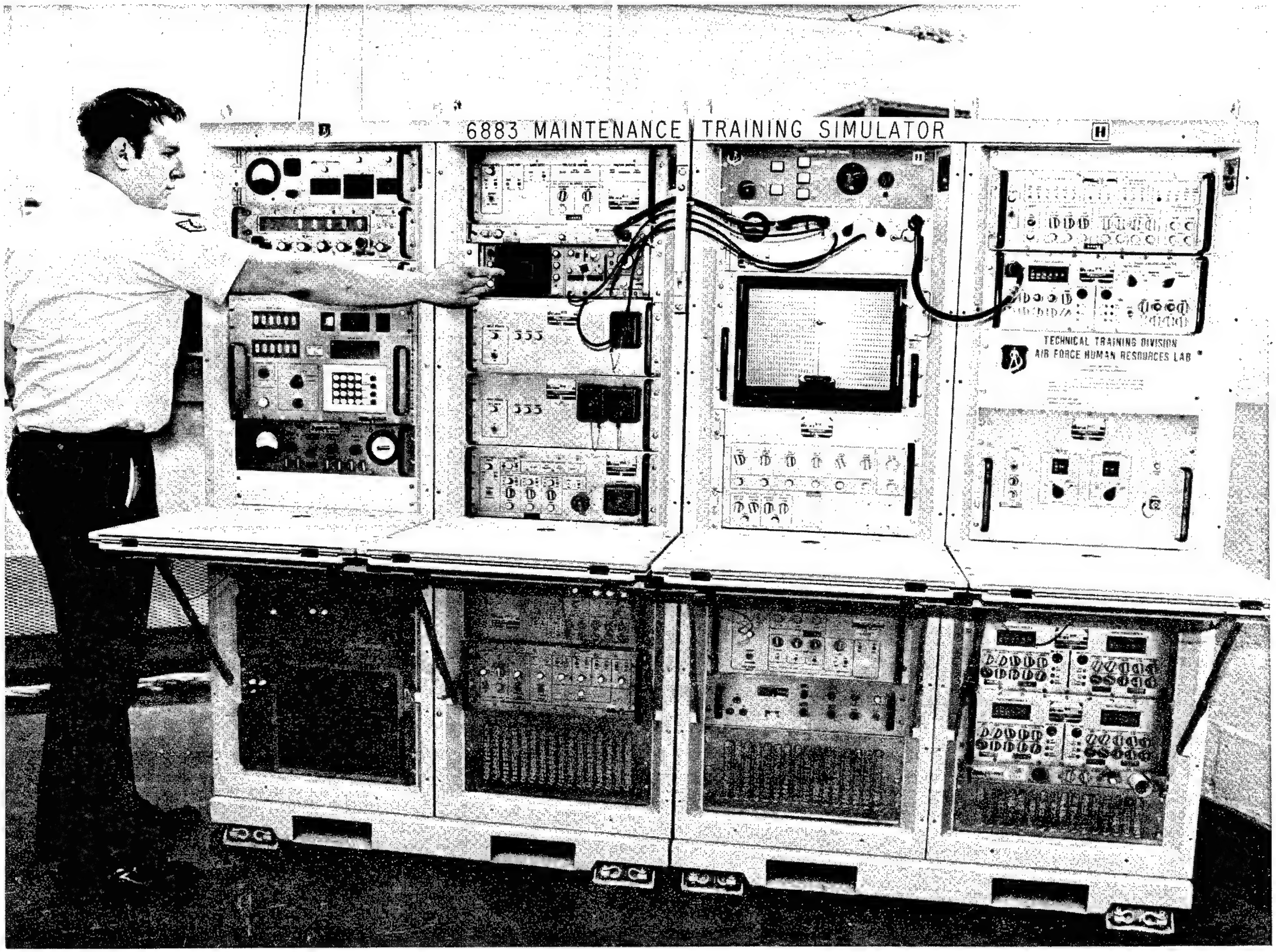

Figure 7. 6883 Test Station Simulation 1735

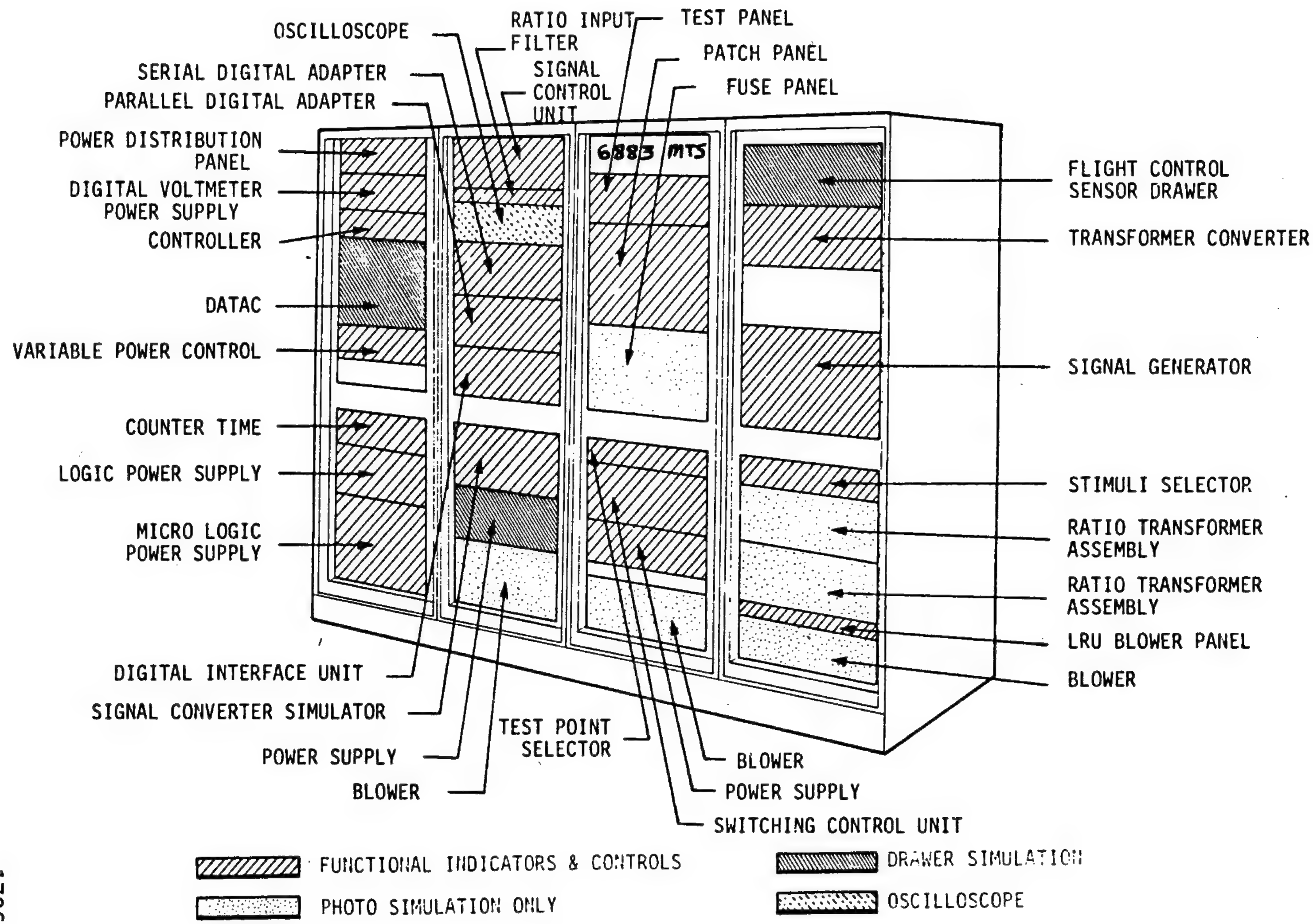

Figure 8. Panel-by-Panel Summary of Simulation Levels Required Across Test Station

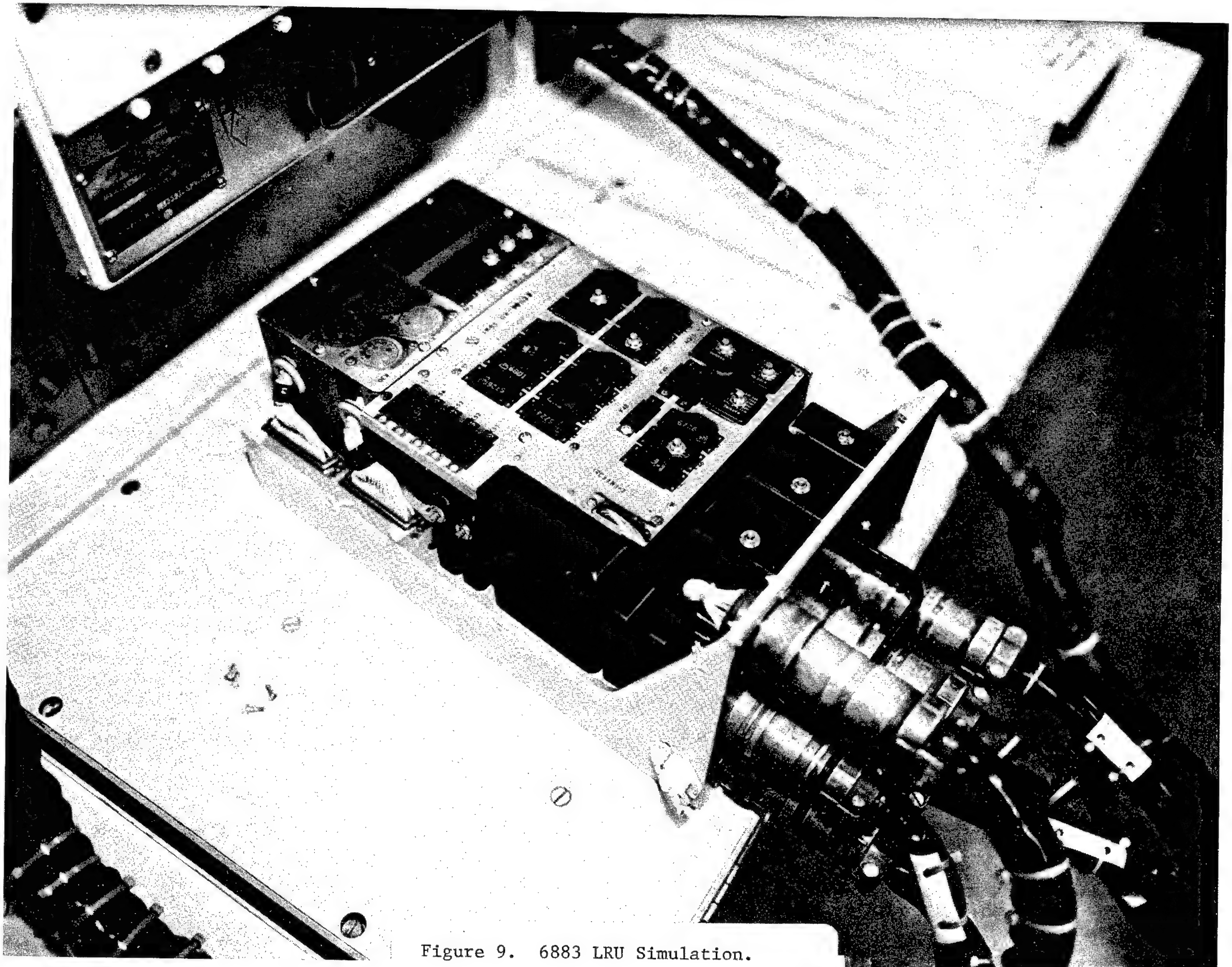

Figure 9. 6883 LRU Simulation.

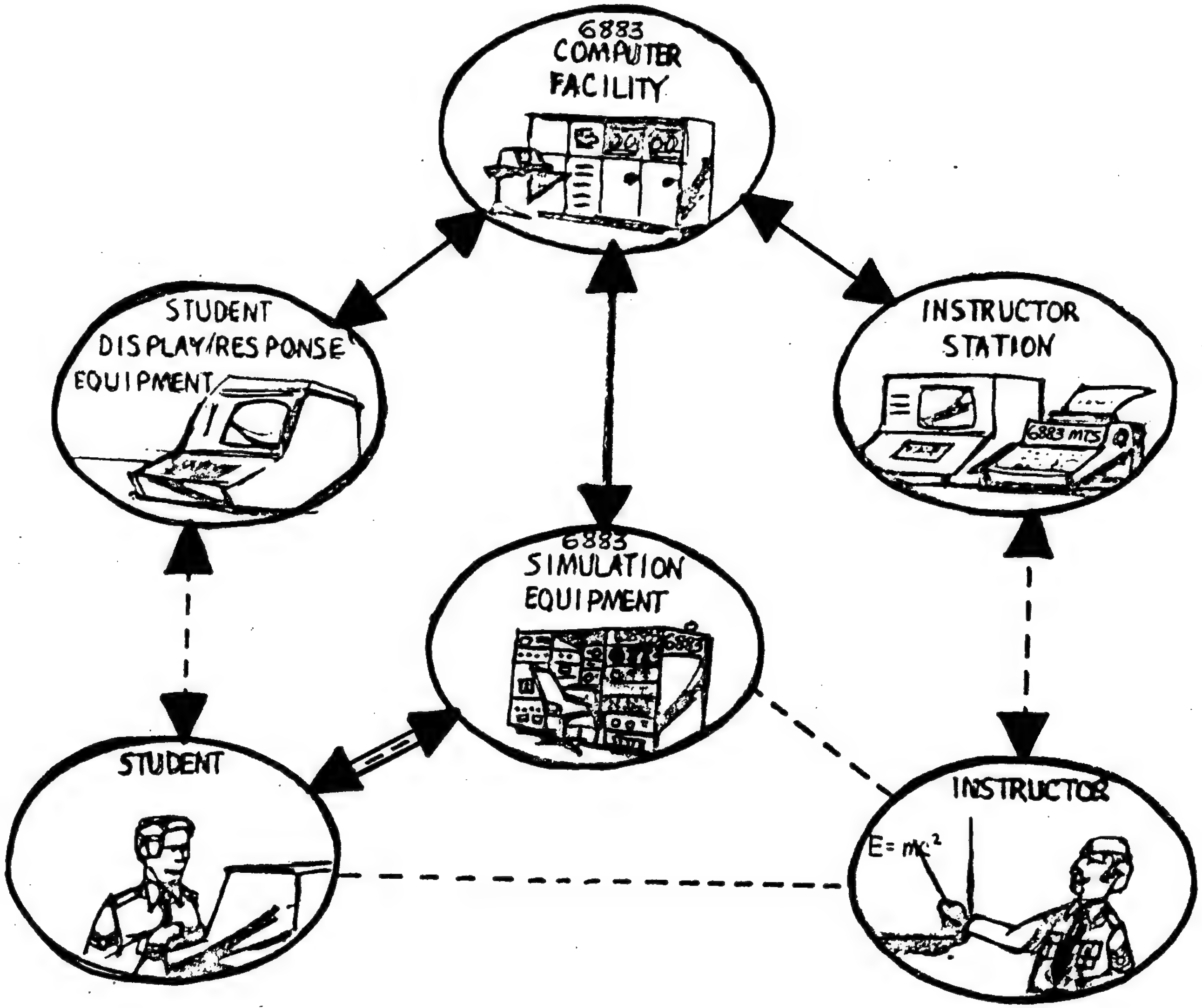

Figure 10. Interactive Computer Based Training in the 6883 Maintenance Training System

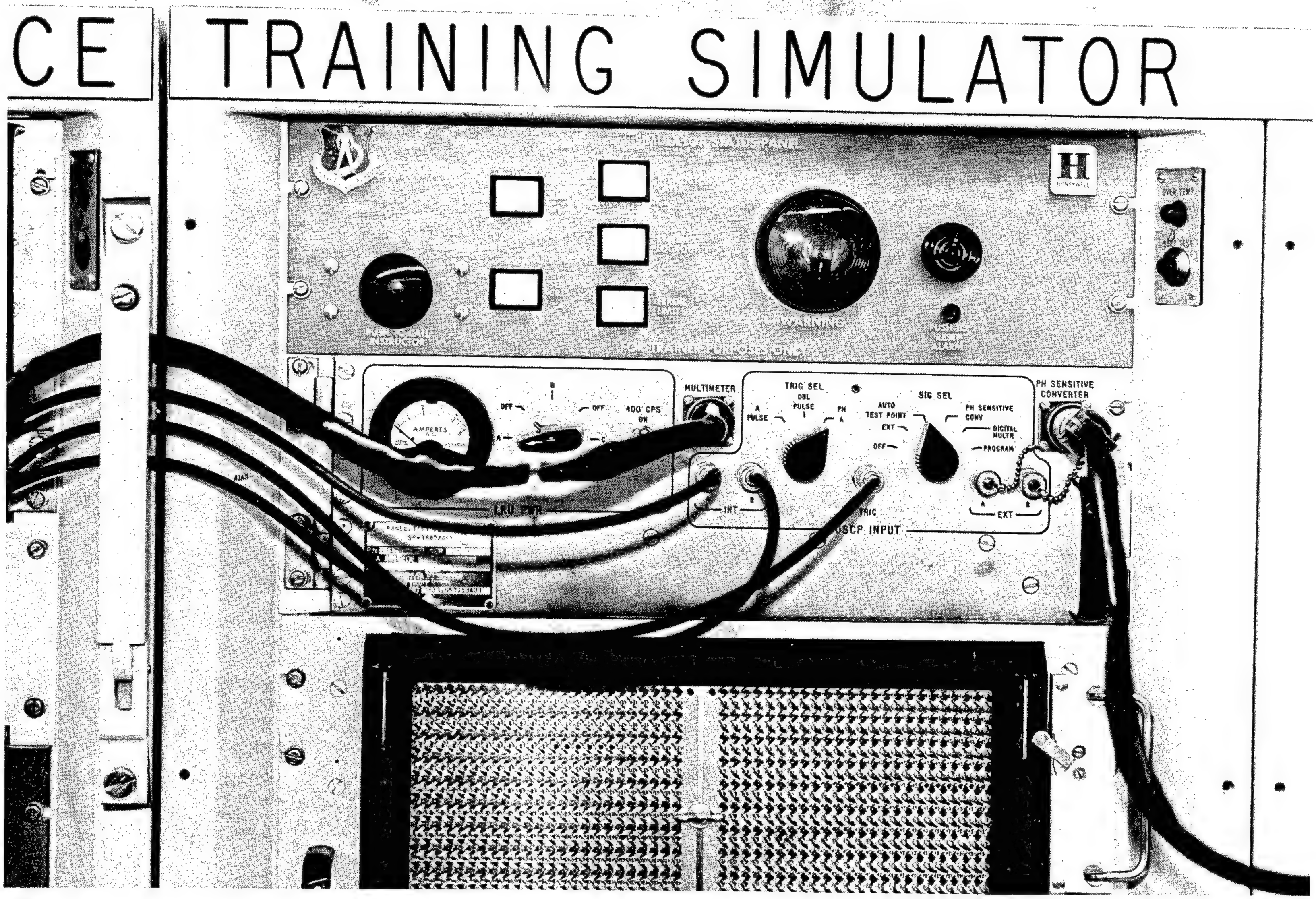

Figure 11. Simulator Status Panel.

```
STATION     STUDENT             CURRENT    PAST      TIME     CUM
               NAME  GARY        CH/PAR    CH/PAR    OVER     ERRORS
  6883    TEST 6        END      C025 91   C121 90             02
  STBY
  STBY
  STBY
  STBY
  STBY
-----------------------------------------------------------------------

PERFORMANCE AT 6883                    LESSON L009     FAULT 09

TIME LIMIT  60                         ELAPSED TIME  07

                  ERROR SUMMARY

ENTRY POINT       00          FAULT DETECT/ISO              01
PROCEDURE         00          COMPONENT LOCN       00

                  CRITICAL         00
                  STUDENT HELPS    00

                  CAI              01
```

Figure 12. Status Log Display

PSYCHOMOTOR/PERCEPTUAL MEASURES FOR THE SELECTION OF PILOT TRAINEES

By

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1741

Psychomotor/Perceptual Measures for the Selection of Pilot Trainees

Abstract

Measures of psychomotor and perceptual abilities have been used for the selection of personnel for flying training since World War II. Early measures showed good validity for the selection of pilots; however, the operational use of those measures was discontinued in the early 1950's--mainly due to calibration and maintenance difficulties with the electromechanical test devices.

Recently, the Personnel Research Division has investigated the use of psychomotor and perceptual measures obtained from modern, solid-state electronic devices. These measures were shown to be valid predictors of pilot training success. Additionally, measures obtained from flight simulator performance have shown to be good predictors of training success.

Future efforts will be directed at the identification and assessment of other measures of psychomotor and perceptual abilities that may be related to performance in flying training. Further research will also be conducted to determine if low-fidelity, "desk-top" flight simulators can be used for the selection of pilot trainees.

Introduction

Flying training is expensive. On a per individual basis, it is probably one of the most costly of the training programs conducted by the military. For that reason, a great deal of attention has been given to the problem of selecting personnel who have the best chance of succeeding in pilot training--the average cost of each person who attrits from flying training in the Air Force Undergraduate Pilot Training (UPT) is now well over $20,000. With a training flow of, say, 2,000 pilots per year and an attrition rate of 20%, this means a loss of over $8,000,000 per year.

The reduction of attrition from UPT, particularly through the development of improved procedures for the selection of trainees, is therefore a matter of considerable concern to the Air Force. As early as World War I, attention was being directed to the development of procedures for the selection of pilot trainees. In 1912, instructions were published for the first medical examination for flying, which was a requirement for entry into flight training (Passey & McLaurin, 1966).

While the possible contributions which psychological testing could make to the selection of pilots were recognized during this period, little work was accomplished until immediately prior to World War II. At that time organizations were established within both the Army Air Force and the Navy containing specialists in aviation psychology. One of their primary concerns was the selection and classification of flying personnel.

In addition to the development of a battery of paper-and-pencil tests for the selection of flying personnel, many tests of psychomotor/perceptual abilities were developed, principally by personnel of the Army Air Corps.

Figure 1 shows the apparatus tests used by the Army Air Corps testing battery in February 1942.

Figure 2 shows the apparatus tests used in June 1945. These tests are described in detail by Melton (1947). Not all of these tests were used for the selection of pilot trainees. The Finger Dexterity test, for example, was used only for the selection of bombardiers.

One of the better known of these tests is the SAM Complex Coordination test. Figure 3 shows the apparatus used in that test. As may be seen from the figure, the apparatus was comprised of a control stick, rudder bar, and an array of lights. The examinee would manipulate the control stick and rudder so as to line up pairs of lights in the array. Measures obtained from this device--the number of matches obtained in a given time--were found to reliably predict later performance in pilot training (correlation on the order of .25).

While this test and some of the others shown in Figure 2 could contribute to the identification of potentially successful pilot trainees, their use in the operational screening process was discontinued in 1955. This came about as a result of the dispersal of the applicants to be tested and also because of the logistic problems involved in apparatus testing--especially the difficulties inherent in the calibration and maintenance of devices which used the electro-mechanical technology of that period.

From that time until very recently, little attention was given to the use of psychomotor/perceptual measures for the selection of personnel for entry into Air Force UPT.

Laboratory Tests

Two developments have brought about a reawakening of interest in the use of psychomotor/perceptual or, more generally, apparatus tests, for the selection of pilot trainees; (1) the ready availability of reliable, solid-state circuitry for use in testing devices; and (2) an apparent peaking out of validity for paper-and-pencil tests. The use of solid-state devices for testing would mean that many of the calibration and maintenance difficulties that beset the World War II electro-mechanical devices could be eliminated and, possibly, reliable test devices produced would be light, compact, and relatively inexpensive.

Experience from the research conducted during World War II had shown that psychomotor/perceptual tests, for the most part, had little overlap with paper-and-pencil tests and that useful increases in validity could be effected through their combination with paper-and-pencil tests in a selection battery. Continual revisions to the paper-and-pencil selection batteries had resulted in the development of an instrument, the Pilot Composite of the Air Force Officer Qualifying Test, that could reliably predict performance in pilot training to an acceptable degree (correlations on the order of .40 - .50); however, in a group, paper-and-pencil testing situation, the range of abilities that may be assessed is limited, and it becomes difficult to increase the validity of the paper-and-pencil battery.

As a consequence, the Personnel Research Division undertook the study of new procedures for the measurement of psychomotor/perceptual abilities. Under contract, a laboratory facility was constructed and two tests of psychomotor/perceptual ability developed. This laboratory system consisted of a PDP-8/L minicomputer interfaced to the two test stations shown in Figure 4.

As shown in Figure 4, each test station consisted of a direct-view cathode ray tube display, two hand controllers, a large, floor-mounted joystick, and a rudder bar. The use of a minicomputer based system was selected because of the flexibility which this system afforded in the alteration of testing procedures and the development of new tests.

The two tests which were initially implemented on this system were modeled after the psychological test characteristics of their World War II namesakes: Two-Hand Coordination and Complex Coordination (Sanders, Valentine, & McGrevy, 1971).

Shown in Figure 5 are the displays used in both of these tests.

In the Two-Hand Coordination test, the examinee uses the two table-mounted joysticks, one in each hand, to control the position of an X-shaped cursor on the screen. The left stick controls vertical movement, the right stick horizontal movement of the cursor. Instructions to the examinee require that he maintain the position of the X as close as he can to a triangular target which moves in a circular path at varying speeds. This test is scored by summing the absolute displacements from the cursor to the target in the X and Y axes over some specified time interval. Typically, a 1-minute interval was selected. The test consisted of 3 minutes of directed practice followed by 5 minutes during which performance measures were recorded; thus, ten measures were obtained--one per axis per minute.

In the Complex Coordination test, the examinee is required to manipulate the floor-mounted joystick to control the movement of an X-shaped cursor while at the same time using both feet on rudder pedals which control a short vertical line which hovers near the bottom of the screen. Instructions to the examinees require that he hold the cursor stationary at the intersection of the fixed vertical and horizontal line of dots while keeping the vertical line aligned with the vertical line of dots. Error scores, that is, summed absolute displacements from the cursor to the intersection, are recorded separately for the X and Y axes for each minute of the test. In addition, the error score for the vertical line under control of the rudder bar is recorded for each minute of the test. Like the Two-Hand Coordination test, there is a 3-minute directed practice period followed by 5 minutes of testing.

The measures taken from both of these tests were found to successfully predict later performance in pilot training. Figure 6 shows the mean scores obtained by three groups on the Complex Coordination test. It may be seen from this figure that the group with the highest score, and hence the poorest performance since these are error scores, consisted of those individuals who were eliminated from Undergraduate Pilot Training due to Flying Training Deficiency (FTD). The group with the lowest score, and hence the best performance, consisted of those individuals who graduated from pilot training (McGrevy & Valentine, 1974).

The results obtained from the Two-Hand Coordination test are similar, although not so dramatic, as those displayed in Figure 6. In general, the Complex Coordination test is superior to the Two-Hand Coordination test in the selection of pilot trainees. These results have been replicated with approximately the same outcomes in two follow-on studies (cf. Hunter & Thompson, 1978).

Portable Test Devices

As a result of the success obtained from the laboratory versions of these two tests, it was decided to develop a portable, self-contained device for the administration of these tests at field locations such as at the Armed Forces Examining and Entrance Stations (AFEES) or Reserve Officer Training Corps detachments; the concept was to take the test to the examinees rather than have examinees brought to a central screening point.

Like the laboratory verison, the portable test device has two table-mounted joysticks, a floor-mounted joystick, rudder-bar, and a cathode ray tube display. The instructions to the examinees and the displays used during the tests are also virtually identical to those used in the laboratory version.

This unit provides for completely automated presentation of instructions, via a cassette tape, and automatic testing and scoring. As before, scores are summed absolute deviations from the cursors to the target points; however, the time interval over which scores are recorded has been altered. Analyses of data taken from the laboratory versions of the two tests indicated that most of the useful information was obtained from performance in the final 2 minutes of the test cycle. Therefore, the portable device records and displays only the summed error scores from the last 2 minutes of each test. Separate scores are obtained for each of the axes, however, so that for the Complex Coordination test three scores are obtained while for the Two-Hand Coordination test only two scores are obtained.

Initial field trials conducted both at Lackland Air Force Base and at various ROTC detachments have shown this device to be rugged and reliable and easy for inexperienced personnel to operate. Data is now being collected using these devices on personnel entering pilot training at Williams AFB, Arizona, and on cadets at the Air Force Academy who are slated to enter pilot training. This data will be used to further validate the use of these tests for the selection of personnel for flying training and to obtain additional feedback from field personnel on ways in which the design and operation of the devices may be improved. This information will then be used to improve the design and characteristics of production versions of the devices which may be used in the operational selection of pilot trainees.

Learning Ability

In addition to the approach taken in the design of the tests described above--that is, the measurement of relatively pure basic abilities--another approach subsumed under the title of psychomotor/perceptual measures involves the measurement of an individual's capacity to learn a task or complex series of tasks--in this case the task of flying an aircraft.

It has long been noted that the best way to select an individual for a position is to simply put him/her in that position and observe his/her performance. Thus, the best predictor of success in flying training is flying training. This is the notion that underlies the use of the light-plane (T-41) screening program used by the Air Force. This process measures the ability of the individual to learn the same or very nearly the same tasks that will be later required in the training program; the closer the similarity between the initial or test tasks and the final task, the higher the validity should be of the procedure.

To investigate that approach outside of an actual aircraft cockpit, the Personnel Research Division, through a contract with McDonnell Douglas Corporation, developed the Automated Pilot Aptitude Measurement System (APAMS). The hardware of the APAMS consists of two modified Singer-Link GAT-1 light aircraft simulators interfaced to a small minicomputer (Varian 620-f/100). Feedback to the examinees was provided by a cathode-ray tube display mounted above the instrument panel and by a Votrax voice synthesizer. Instructions to the examinees were given via a Bell and Howell filmstrip system mounted to the left of the examinee in the cockpit (Long & Varney, 1975).

The instructional system used in this study assumed no prior flight experience on the part of the examinees. Therefore, all examinees received instruction in the purpose and use of controls (e.g., throttle, control wheel) and instruments before receiving instruction in how to perform flight maneuvers. The syllabus of instruction required approximately 5 hours, divided into five session of about 1 hour each, spread over 10 days.

After learning the basic functions of the controls and instruments, the examinees learned how to fly the simulator in straight-and-level flight, how to perform turns and descents, and, by the end of the 5th hour, were performing take-offs and landings and flying an airport traffic pattern.

During each stage of the learning process, performance was measured automatically by the computer. Measures were in terms of deviations from the command or ideal state of flight parameters such as heading, altitude, and airspeed. This process generated 190 measures of performance at differing stages of learning. Factor analysis and other data reduction procedures eventually reduced this number to approximately six scores which could parsimoniously describe the examinees performance.

From these analyses, it was found that measures of Heading, Bank, and Altitude control could reliably predict later performance in pilot training. In fact, these measures were superior to either the paper-and-pencil or psychomotor coordination tests in the prediction of outcomes in pilot training. (Zero order correlations on the order of .20-.35).

Summary and Conclusions

These studies have shown that measures of psychomotor/perceptual abilities may be reliably assessed and that such measures are valid predictors of later performance in pilot training. Furthermore, these measures are relatively independent of those abilities assessed through the use of conventional paper-and-pencil tests. This means that psychomotor/perceptual measures may make significant contributions to the existing selection procedures which, except for the physical examination, rely exclusively on conventional paper-and-pencil tests.

The measures considered thus far are, of course, by no means the only ones that may prove useful. Indeed, the present research has barely begun to identify those psychomotor/perceptual abilities that may be related to success and failure in pilot training. Other abilities measured during World War II, such as choice reaction time, and more recently identified measures such as information processing ability as measured under high load conditions, may also prove relevant.

The future research to be conducted in this area will seek to identify more of these abilities that are related to pilot training outcomes and to develop reliable and inexpensive instruments for their assessment. In addition, procedures for the measurement of abilities already identified will be improved.

In the laboratory, the relation between learning ability, as measured by the APAMS, and success in pilot training has been established. However, the devices used in the laboratory are totally unsuitable for use in an operational selection system. The next step in this area will be to develop an inexpensive, portable device for the assessment of learning ability, and this will be accomplished in the near future.

The design of an effective pilot selection system, like the design of a weapons system, is, in the end, directed by cost-benefit relationships. It is not sufficient to design a valid selection test without at the same time considering the eventual acquisition and operation costs of that test in comparison with the savings to be realized through decreased attrition or improved personnel effectiveness.

These factors will continue to be considered during the design and development of new psychomotor/perceptual tests so that these instruments can make a positive impact upon the reduction of training costs and the improvement of personnel utilization in the Air Force.

Biographical Sketch

Mr. David R. Hunter was born in Texarkana, Arkansas, on 12 March 1945. He graduated from the U.S. Army Rotary Wing training program in 1968 and spent the succeeding 3 years as a pilot and flight instructor. After leaving the service, he returned to college and received a B.S. degree in Psychology from the University of Texas at Arlington in 1973. Mr. Hunter has received graduate training in educational psychology at the University of Texas at Austin and is now a candidate for the PhD degree.

In July 1973 he began employment with the Air Force Human Resources Laboratory. His principal interests have been in the areas of computer-assisted and perceptual/psychomotor testing, especially as they relate to the selection of personnel for flying training. He has published three papers in these fields since 1973. Mr. Hunter is currently engaged in the development of an automated measurement system to be used in the development of psychomotor/perceptual and adaptive testing procedures and is continuing studies directed toward improved pilot selection. He is also engaged, as the topic of his dissertation, in research evaluating the use of computer simulations in the development of adaptive testing procedures.

He is a member of the Association of Aviation Psychologists.

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APPARATUS TESTS U. S. ARMY AIR CORPS

WORLD WAR II

FEBRUARY, 1942

COORDINATION

FINGER DEXTERITY

FEEL OF CONTROLS

SERIAL REACTION TIME

Figure 1.

APPARATUS TESTS U. S. ARMY AIR CORPS

WORLD WAR II

JUNE, 1945

SAM ROTARY PURSUIT WITH DIVIDED ATTENTION

RUDDER CONTROL

FINGER DEXTERITY

SAM COMPLEX COORDINATION

SAM DISCRIMINATION REACTION TIME

PEDESTAL SIGHT MANIPULATION

Figure 2.

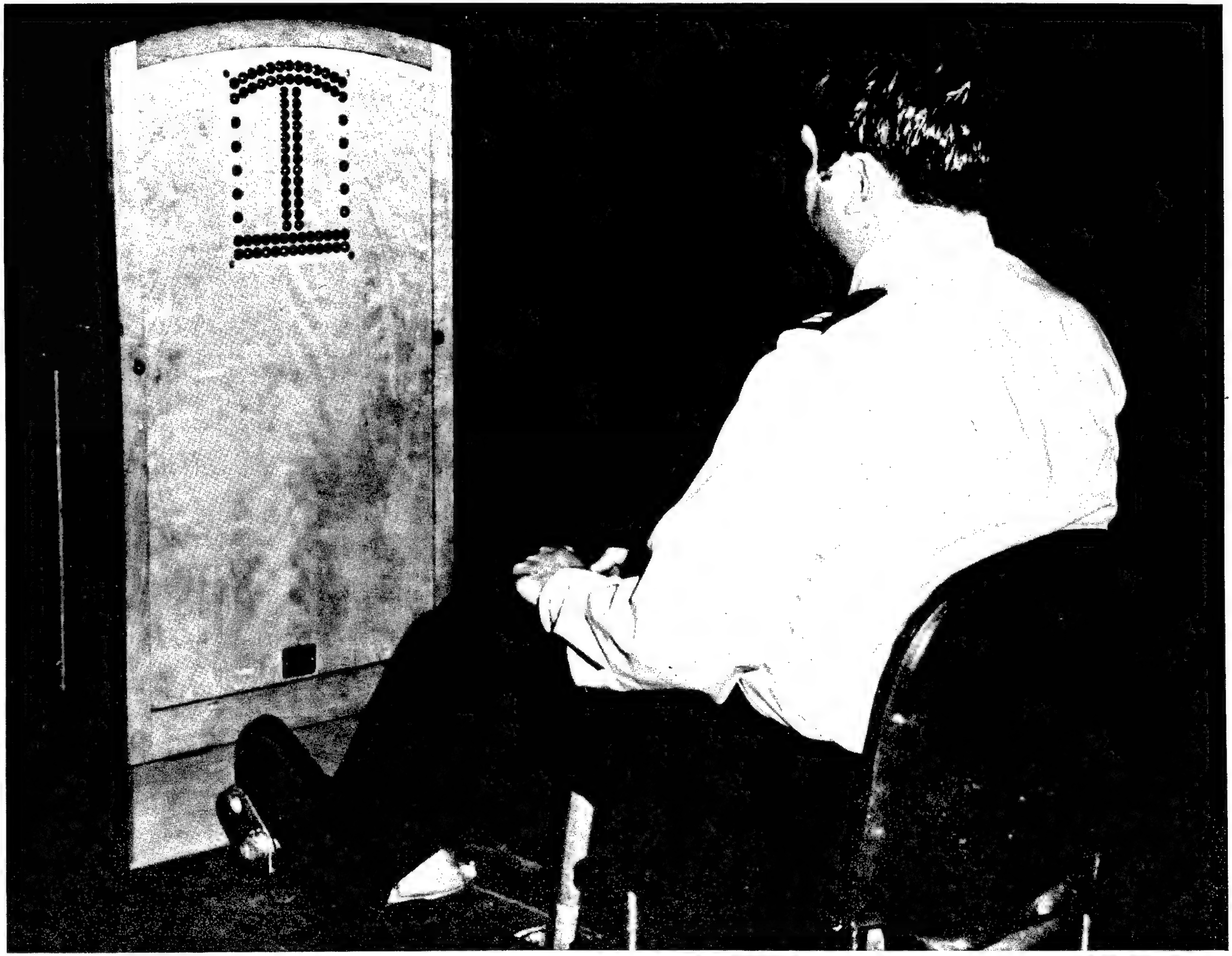

Fig.3 SAM Complex Coordinator Test 1753

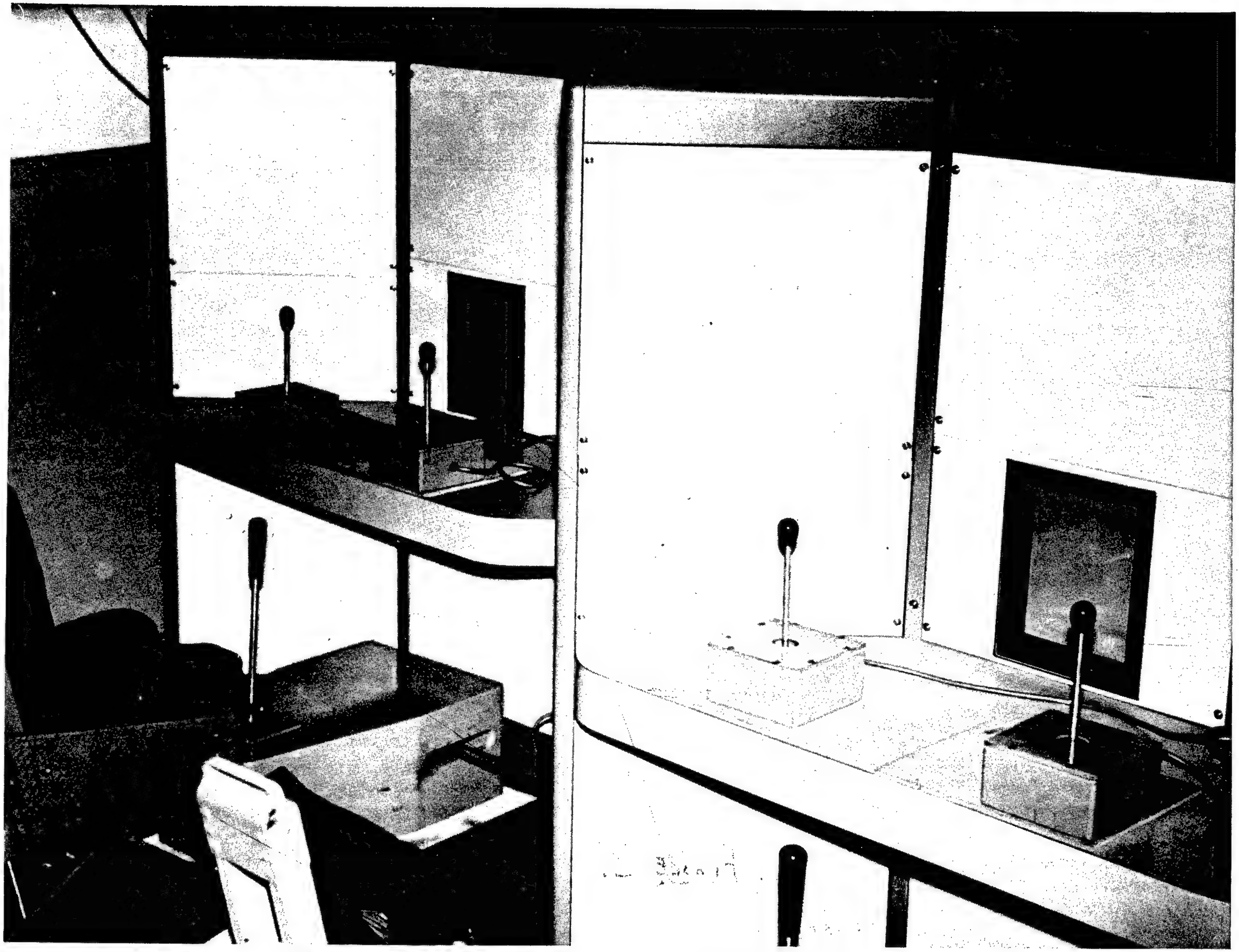

Fig.4 laboratory Psychomotor Test Stations 1754

COMPLEX COORDINATION TEST

TWO-HAND COORDINATION TEST

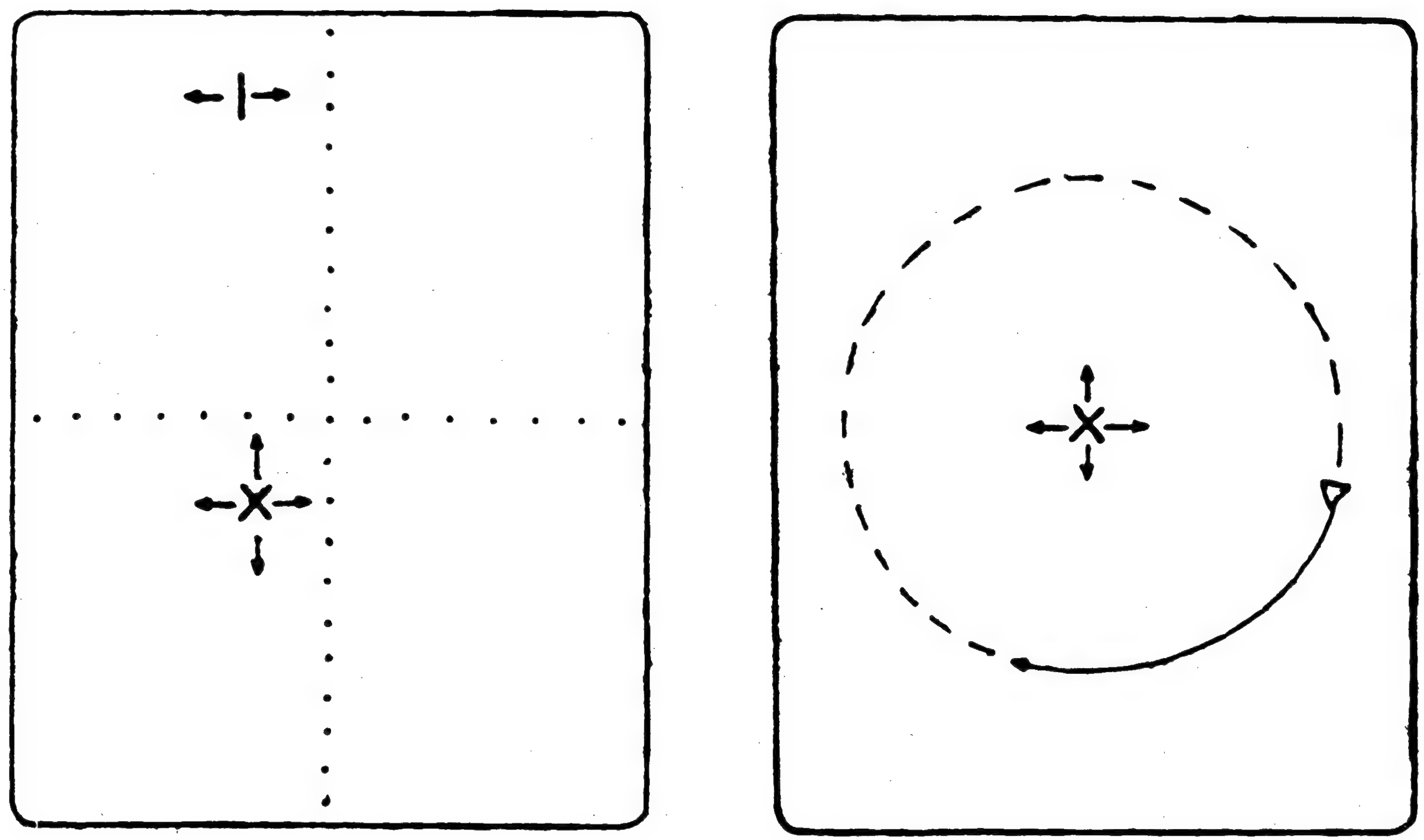

Fig.5 Psychomotor Test Displays 1755

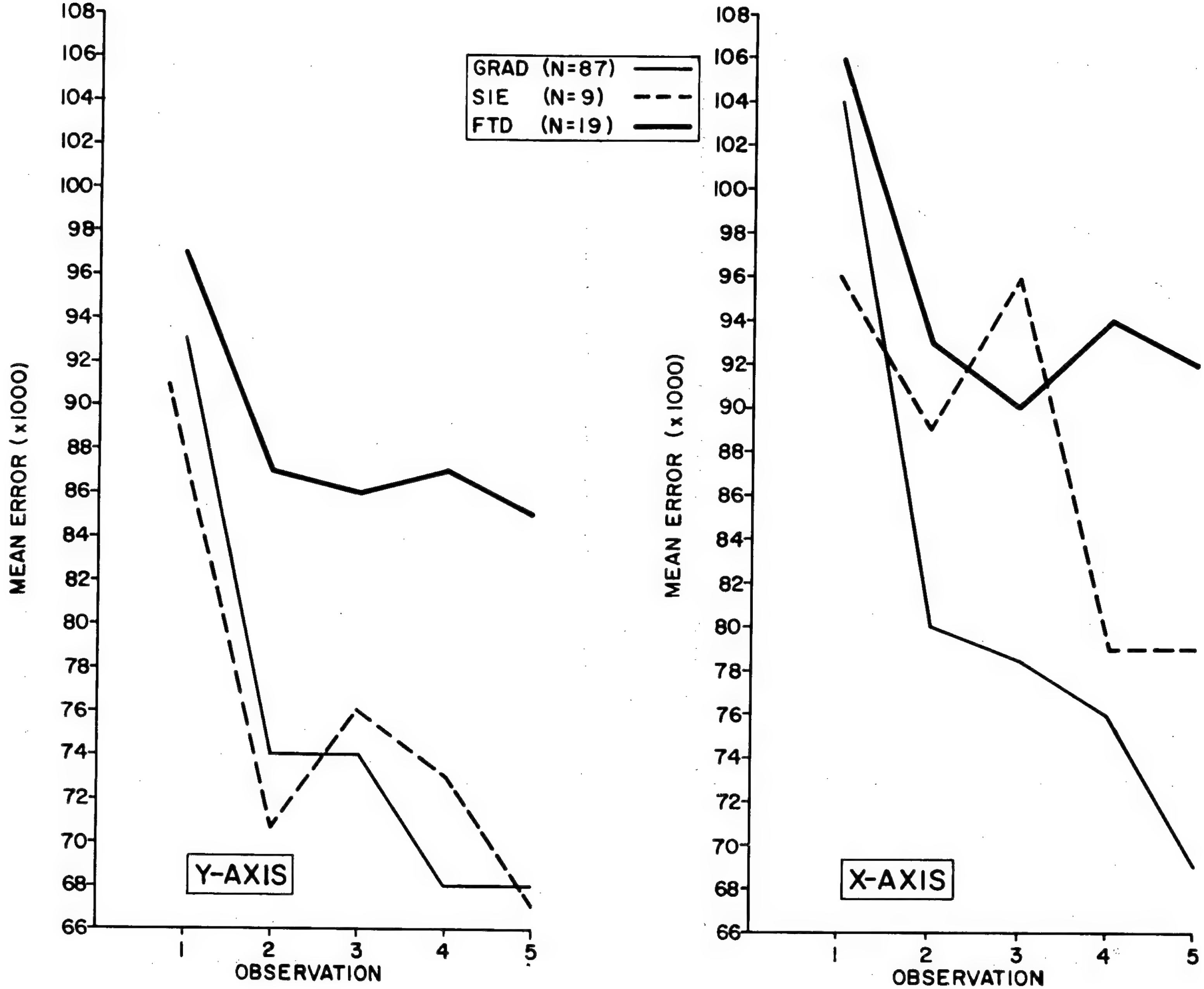

Fig.6 Psychomotor Test Performance curve 1756

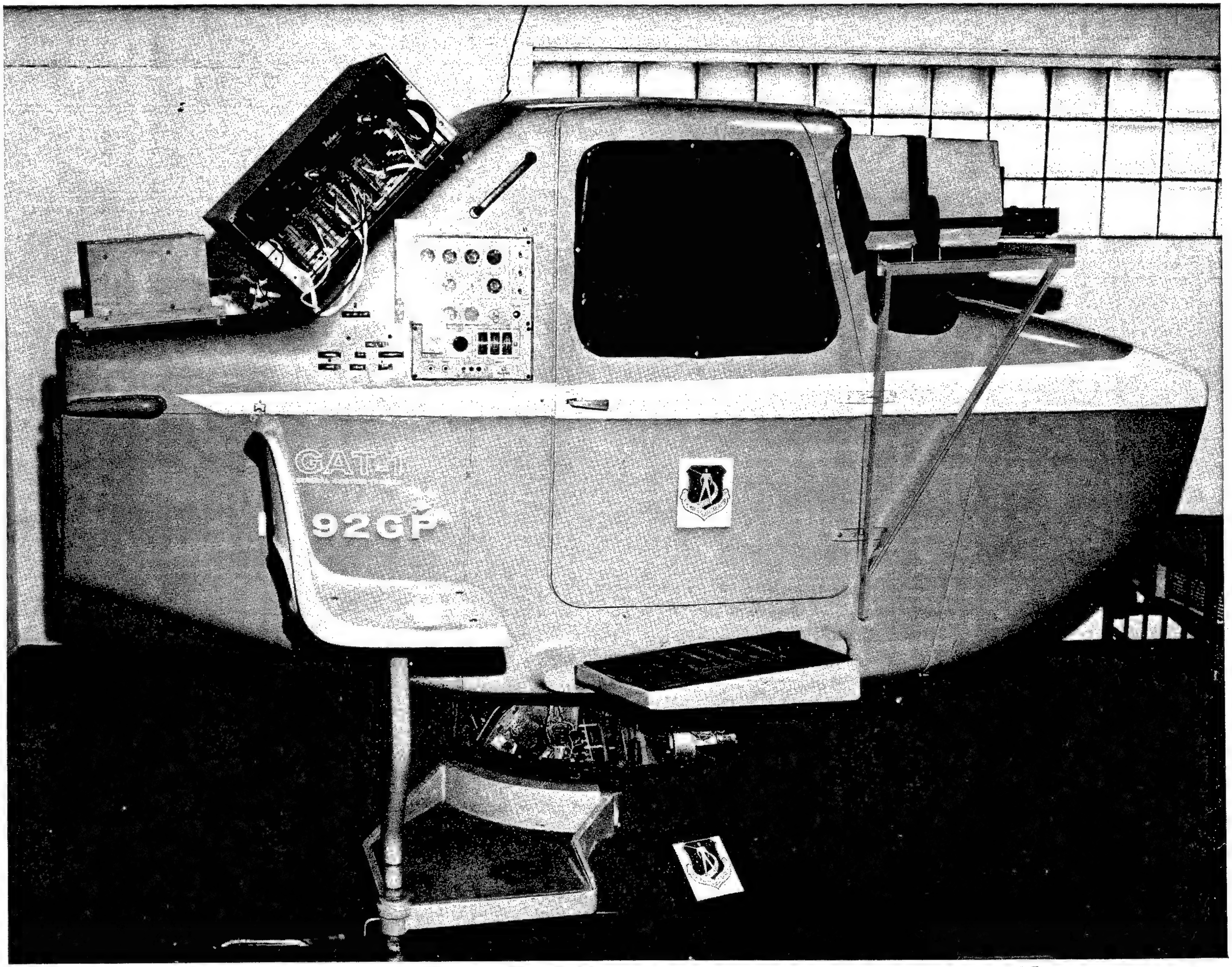

Fig.7 Automated Pilot Aptitude Measurement System 1757

MODERN MAINTENANCE TRAINING TECHNOLOGY AND OUR NATIONAL DEFENSE POSTURE

BY

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Abstract

This paper presents the case for using simulators and other new training technologies rather than costly actual equipment to teach hands-on troubleshooting skills to maintenance technicians. The likely impact of these newer synthetic training devices on fleet readiness and cost parameters is discussed. The presentation identifies the danger of trying to solve the technical training problem with one-sided solutions which do not take advantage of modern training techniques.

Introduction

We have some good news, and some bad news. The good news is that the high cost of maintenance for DoD equipment is not the major problem to be discussed in this paper. Yes, you've heard the figures that maintenance accounts for twenty to twenty-five percent of the total annual DoD budget. (Rowan, 1973), and you may have even seen the data to the effect that it costs DoD one hundred million dollars per year just to train electronics technicians (Bruns, 1975). One example that seems relevant here is shown in Figure 1 where Repair Labor, as a life-cycle cost element in the A-7D aircraft weapon system, was essentially equal to the initial purchase price of the system, plus the cost of operating it, including pilot salaries. But we're not going to dwell on the costs of maintenance per se.

You can get a hint of the nature of the bad news from the fact that even if we allocated twice the money we now spend on troubleshooting and repairing our complicated weapons systems, we probably wouldn't use it any more judiciously than we now utilize our present budget. The bad news, ladies and gentlemen, is that the major problem facing DoD today is one of readiness. The discomforting fact is that if we cannot improve our readiness posture beyond what it is today, we simply are not going to survive long enough to worry about the finer points of Repair Labor cost.

Let's take a brief look at our readiness posture. The continuing Soviet buildup, and simultaneous waning of American military superiority has not escaped notice, with the alarm even being sounded in the respected journal Foreign Affairs (Gray, 1978; Head, 1978). Current figures prepared for the Chief of Naval Operations (Understanding Soviet Naval Developments, 1978) show the results of recent Soviet Naval increments during a period in which the size of the U.S. Navy decreased by over 50 percent. Figure 2 tells the story: the Soviet Navy is the world's largest in terms of numbers of ships, outranking us in overall tonnage and outnumbering us in every category except aircraft carriers. They are embarking on a carrier-building enterprise which will put them essentially in control of the seas.

But how about missilery? Surely our "technological superiority" will sparkle in this category. Unfortunately, Gray (1978) has predicted that by the early-to-mid-1980's,

we may have to accept that all or nearly all of our silo-housed missile force would be destroyed by a Soviet first nuclear strike.

Another surprising fact is shown in Figure 3, which illustrates how Soviet R&D expenditures have grown until their outlays exceed those of the U.S., and how those efforts have led them to be able to outspend us in weapons procurement and military construction by two to one in 1976. Figure 4 compares U.S. and Soviet production rates for several military categories. These figures show them out-producing us eight to one in artillery, six to one in tanks, three to one in infantry fighting vehicles, two to one in tactical aircraft, and with slight advantages in helicopters and anti-tank missiles.

Are We Ready?

While Americans are justifiably proud of the sophistication of their weapon systems, that very sophistication can have serious consequences for readiness. In an interesting perspective on U.S. and Soviet R&D systems, Head (1978) presents convincing arguments against any fond hope that Soviet weaponry is likely to be in a worse state of readiness than ours. For example, Soviet weapons designers may have the materials and training to develop more advanced designs, but their efforts are circumscribed by several constraints. First, they must use centrally-approved designers' handbooks that specify research results, an approved list of structures, design forms, components, materials, and manufacturing techniques. They are also restrained by lack of sophistication in production technology, low technical level of Soviet troops, and a doctrine that military capabilities are enhanced more by large numbers of deployed weapons with modest individual characteristics than by smaller numbers of higher quality weapons. These factors produce a conservative design simplicity, interchangeable parts, and evolutionary growth (Alexander, 1976).

By contrast, U.S. weapons development is oriented toward high performance. U.S. military requirements call for high performance and low attrition rate, and U.S. industrial contractors respond with proposals for revolutionary developments, new subsystems, and sophisticated design. This design approach has often produced overly

complex, expensive, and less reliable systems. As you would expect, the sophistication of U.S. weapons systems has tended to generate higher maintenance manpower and training costs and higher support costs (Head, 1978).

The readiness implications seem clear. Put it this way: You might feel pretty confident if you could have an F-14 aircraft armed to the teeth assigned exclusively to protect your home. But consider what happens on the day your F-14 has its Constant-Speed Drive in the shop for repairs and someone comes down your street driving a tank with a manual transmission, a manual, lever-type steering mechanism, and a 40-year old engine design. The Soviet T-62 tank is just such a tank. Uncomplicated and unsophisticated? Perhaps. But you can bet if they want to use it, it will be ready!

While there are data to support the above sensationalist scare tactic, they are very preliminary, and we do not want to designate the exact type of weapon system involved, nor the exact findings. And, of course, any open discussion of American readiness factors would overlook the sensitive nature of such topics to our national defense. Let us just say that "a recent study" shows that the number of weapon systems cited in our favor at the SALT tasks in Geneva are an over-estimate of the real number of systems remaining after agedness, mean-time-between-failure, and maintenance errors have all taken their toll.

In efforts such as the "recent study" above, we can show that a particular group of aircraft are NOR (Not Operationally Ready) due to specific combinations of maintenance errors, faulty procedures, and/or poor sparing policies. And we can simulate the possibilities of reducing that NOR figure by half without expending over one-tenth of the cost of adding another aircraft. The question then becomes one of achieving that reduction using purely the Human Factors and Human Resources approach. In the section below, we want to lay to rest some current and proposed approaches that won't help us reach that objective.

What Won't Work

Hardware Solutions. "Hardware" solutions to today's costly maintenance problems are suspect from the start because we know that maintenance and readiness both rely heavily on people systems. In the Apollo Program, it was

the human astronaut who provided the manual backup in many cases to provide mission reliability. Manufacturers' claims regarding ATE, BITE, and "Smart" instruments notwithstanding, it is ultimately the human technician who winds up troubleshooting the really tough malfunctions. Figure 5 summarizes results of one study where the promised MTBF was in every case more glowing than the eventual MTBF in the real world (Pyatt, 1972).

Another example comes from the largest single deployment of ATE (Automatic Test Equipment) in military history, viz. the Navy VAST system. While this workhorse has accomplished much of its mission, it has, at the same time, created a "vast" number of gray-haired technicians. True to the Hardware-Solution tradition, VAST was supposed to require an operator and technician with only minimal training. Unfortunately, such a concept presupposes that the program will be perfect, the machine will always operate properly, and documentation associated with the testing process will always be up-to-date and correct. Experience has shown that such conditions seldom prevail in spite of the most stringent efforts. In the end, the VAST program has had to:

- realign training to include advanced operator and intermediate maintenance courses, including off-line maintenance procedures, calibration, self-test, and in-depth theory.

- acquire supplemental data such as diagnostic flowcharts, string lists, test diagrams, and program listings to provide troubleshooting data when the test program does not provide the right answer.

- invent training for a new kind of technician called a Test Program Set Analyst, whose job it is to try to make sense out of it all.

The VAST experience is generally applicable across several types of ATE, and the magnitude of the resulting maintenance readiness problem can be grasped from the fact that acquisitions of ATE amount to 500 million dollars annually in the Navy and 700 million in the Air Force (King and Duva, "Overview" 1978).

Minimize training, maximize Job-Performance Aiding. There is a sizable effort mounting in DoD to replace training with Job-Performance Aids (JPAs) which tell the technician exactly what to do in the work setting. Experiments have been cited where high school graduates first receive a few hours instruction on how to use this "cookbook" approach for checking out a piece of equipment. Their performance on checkout of an actual piece of equipment is then compared with that of a group of seasoned veterans. For the particular tasks studies, the veterans did no better than the high-schoolers.

Unfortunately, the minimized training, maximized aiding approach suffers from a number of critical drawbacks:

(1) Ignores Typical Navy Environments. Work environments in military services other than Navy are typically accessible by land transport and re-supply; thus space is not the critical issue that it is in, for example, the submarine Navy where eight tons of displacement must be provided just for the life support of each man taken aboard. The latter environment cannot tolerate the concept of several lesser-trained individuals backed up by a senior technician. Each man must be a professional, and he must even be crossed-trained in areas not orignially his own. In the NAVAIR case, the cramped quarters of a carrier-based aircraft are only slightly relieved when the airplane lands on the deck of a floating platform which has its own re-supply problems.

The space/re-supply problem has important implications for maintenance training in that the technician must be able to (a) diagnose and repair systems down to the component level, a requirement that rules out the use of simple checklists which rely primarily on a diagnose-by-replacement strategy, and (b) operate without the voluminous documentation that it would take to provide step-by-step instructions for troubleshooting complicated systems at the Intermediate Level of difficulty. The situation is somewhat as shown in Figure 6 where we see the Navy technician having a sizable system responsibility with only limited space available for spares and/or documentation. As a result, we must make sure he has mentally stored sufficient principles and hands-on training to cope with the problems that he undoubtedly will encounter in the Fleet.

(2) Concentrates on Outmoded Paper-Covered Aiding. What could be more efficient than a simple sheet of paper that tells the technician exactly what to do? First, there is no assurance that that sheet will prove to be any better than the standard technical manual in terms of its update capability. In fact, its necessary specificity could cause the checklist to be even more sensitive to update requirements and thereby more conducive to maintenance error than the familiar tech manual which presents only general system information.

Aside from the likelihood that paper-covered JPAs will exhibit early obsolescence in a system's life cycle, it is inconceivable that a pre-composed, printed, and published JPA can be written for troubleshooting complex systems down to the component level. Our disbelief here stems from the simple possibility that a malfunction occurring on a particular system under specified conditions may never have occurred before to a JPA author. In other words, it is difficult to conceive of a step-by-step guide (ignoring the volume of paper that would result) for troubleshooting individual malfunctions of a complex system, when even it's designer might not know what would happen under many circumstances.

(3) Mission Success Hinges Upon Only a Few Individuals. The concept of only a few individuals trained to a professional level on a weapon system (who oversee the JPA-based activities of a number of technicians) sets a dangerous precedent in terms of tactical warfare. One professional JPA Specialist in remarking on the ill-fated rush to provide FPJPAs to the Vietnamization effort, concludes that "The studies conducted to date reinforce the feasibility of integration of the JPA approach into the documentation system, but not replacement of the existing system with JPAs -- an intent that many erroneously inferred from the hastily-assembled MIL-J-83302." (Joyce, 1975, pg. 11).

While we may not be training our technicians in a most cost-effective and/or training effective manner using time-worn methods, our present state of readiness (or unreadiness, as the case may be) suggests that this would not be an appropriate time to cut out training altogether. As the saying goes, "If you think training is expensive, try ignorance."

Where Do We Go From Here?

One interesting figure on maintenance errors that has been cited since 1973 pertaining to false returns, is that for all of DoD, 30% of the units that are returned as being faulty are, in fact, good (Rowan, 1973). It is, of course, our presumption here that many of these types of errors could be diminished with improved maintenance training both in the classroom and on the job.

In calling for more formal classroom-type training for technicians, Huffman and Rostker (1976) point out that formal training may be less expensive than OJT, and they cite the study by Gay (1974) in this regard. As reviewed by Huffman and Rostker, Gay showed that the OJT cost for Aircraft Maintenance Specialists in the Air Force was approximately twice that of their technical school training, and about half the total cost of the Air Force's first-term investment in the Airman. It is easy to underestimate the cost and extent of OJT; for example, most of us at this conference are learning something from the discussions, that is, we are learning concepts on-the-job.

The point is that maintenance and its logical extension, readiness, both need a fresh approach which looks at the people variables in the entire maintenance pipeline. What we see is a propitious mix of the media represented by the bottommost line of six blocks in Figure 7. In other words, we believe in "traiding" (Training and Aiding) the technician so that he is of both immediate and long term-use to the operating unit. We propose to do this as follows:

(1) Bring together the best of the hardware and publications worlds.

(a) Three-Dimensional (3D) Simulation is the first technique we recommend for hands-on troubleshooting training, and it should be used wherever possible. Abundant data exist to indicate that, for a large part of training, actual equipment trainers (AETs) can be replaced with 3D simulators that are more training-effective than the AETs at one-third the cost or less. Although AETs must still be used at the very final segments of a training syllabus, the 3D hands-on trouble-shooting simulator has a bright future when the 500 million dollar annual purchase

of Navy automatic test equipment is recalled from an earlier section of this paper. Significant numbers of these costly Test Stands are being entirely devoted to technician and operator training. The point is that better training for better maintenance for better readiness can be achieved at less cost by using simulation to reduce our reliance on AETs.

Research on such simulation is ongoing in a few locations throughout DoD, but funding is unsystematic and spotty. The Human Factors Laboratory at NAVTRAEQUIPCEN has fortunately had the unfailing support of a 6.3 NAVAIR program sponsored by CDR Paul R. Chatelier, who is now DDR&E, Military Assistant for Training and Personnel Technology. Under this program, our laboratory has developed a 3D simulator for the A-7E Head-Up Display Test Bench, as shown in Figure 8. Even including the front-end analysis of the training requirements and performance specification, which is critical in the development of simulators like this, the cost of this device is only approaching half that of the actual Test Bench. That's because the simulator doesn't have all the inner electronic wizardry that makes the actual equipment an unreliable, cumbersome, expensive, dangerous, and relatively training-ineffective device. The simulator is reliable and easy to use. The trainee can walk around the unit, pull out drawers, remove cards, and hook up simulated test equipment to test points and diagnose a "malfunction" that has been inserted by the instructor at a keyboard. It permits hands-on Intermediate-Level maintenance troubleshooting training on the Head-Up Display Set and on the Test Bench itself down to the level of components on the printed circuit cards.

There is a 6.3 effort similar to ours being conducted through Dr. Marty Rockway's Laboratory at Lowry Air Force Base, and we have several experimental projects for applying this technology through the three levels of the air, surface, and submarine Navy. It can make training at once more comprehensive, safer for the trainee and the equipment, and less costly.

(b) Automated JPAs and Two-Dimensional (2D) Simulation are the other elements that we would include in the hardware/publications mix. It would be technologically wasteful for today's solid-state digital technology not to be applied to the drawbacks of the publications and simulation used in isolation from each other. For example, one

commercially available device can place 3,000 pages of text (five average books) onto a single 4- by 6-inch microfiche. Interactive computer graphics could be coupled with such a device to teach the novice technician either at the training site or on the job.

While we have accused paper-covered JPAs of being outmoded, newer automated approaches would allow more-responsive delivery systems to be developed which could be made portable and usable on a continuous basis throughout formal training and on the job. For example, a key element of a FOMM (Functionally Oriented Maintenance Manual) in Figure 7 is a Maintenance Dependency Chart which depicts every component in a system in terms of its dependence upon every other. Such printed charts effectively unburden the troubleshooter, but they can now be replaced by an interactive, microprocessor-driven, and highly-portable device that can lead the technician step by step in a fashion not unlike the Fully-Proceduralized Job-Performance Aid of Figure 7. It would, in addition, present troubleshooting sequences to the technician which are generative, that is, made up on the spot rather than pre-printed and published ahead of time with all of the concurrent potential for obsolescence.

Were such a device packaged together with a second unit designed to train the technician as well, we would have a phenomenally useful tech data source that is designed specifically for "traiding" the technician by way of a single device. Research on just such a unit is ongoing at the Human Factors Laboratory, NAVTRAEQUIPCEN, but the effort is in dire need of funding support at the present time. Unfortunately, no more than a fraction of one percent of the annual DoD budget is being spent on maintenance training research, a figure which compares rather unfavorably with the aforementioned 20% to 25% maintenance cost attached to the annual DoD budget.

(2) Full-Facility Implementation.

Now we come to the implementation step of our proposal for a fresh approach to maintenance training and aiding. We would like to try the combination of 3D simulation with automated JPAs and 2D simulation at selected DoD training sites. Once we have successfully put together a winning combination of the presently known "traiding" media, we should be ready for an experimental tryout at selected

training sites. One lesson that we are likely to learn at the outset of such a venture is that we have had an impossible pipeline problem from the very start. In other words, we may find out that there are reasons other than indadequate technician training which account for much of our lack of readiness.

But supposing that we can clean up the maintenance management problems, we should pick training sites in one or more of the services and at least investigate the possibility of simulating and "traiding" the entire set of hands-on courses taught at those sites. Both in dollars and in sense of security, the taxpayer should be happy with the result if we can:

(a) Save two-thirds or more of the cost of an AET by simulation,

(b) Supply the operator/technician of complex equipment with training and aiding information that will assist him both on and off the field of his operational assignment, and

(c) Reduce, in the process, the mean-time-to-repair of a piece of equipment.

The overall point is that modern maintenance training technology can save training dollars while improving our national defense posture.

Biographical Sketches

Dr. William J. King, a former Remote Control System Technician in the U.S. Marine Corps, obtained the B.A. degree in Psychology from the State University of Iowa, the M.A. in Experimental Psychology from the University of Illinois, and the Ph.D. in Experimental Psychology from the University of Sydney, N.S.W., Australia. In the Human Factors field for over twenty years, Dr. King has worked with the man-machine problems of many types of military vehicles such as submarines, conventional aircraft, helicopters, and space vehicles. He has authored a number of Technical Reports and publications, and is now employed as an Engineering Psychologist in the Human Factors Laboratory, Naval Training Equipment Center, Orlando, Florida.

Dr. Paul E. Van Hemel graduated from Hobart College in 1965 with the B.S. degree in Psychology. He continued studies in Experimental Psychology at The Johns Hopkins University, earning the M.A. in 1967 and the Ph.D. in 1970. He subsequently taught at the University of Maine, Portland-Gorham, and at Franklin and Marshall College in Lancaster, Pennsylvania, authoring several articles in professional psychology journals before joining the Human Factors Laboratory, Naval Training Equipment Center, Orlando, Florida in 1977.

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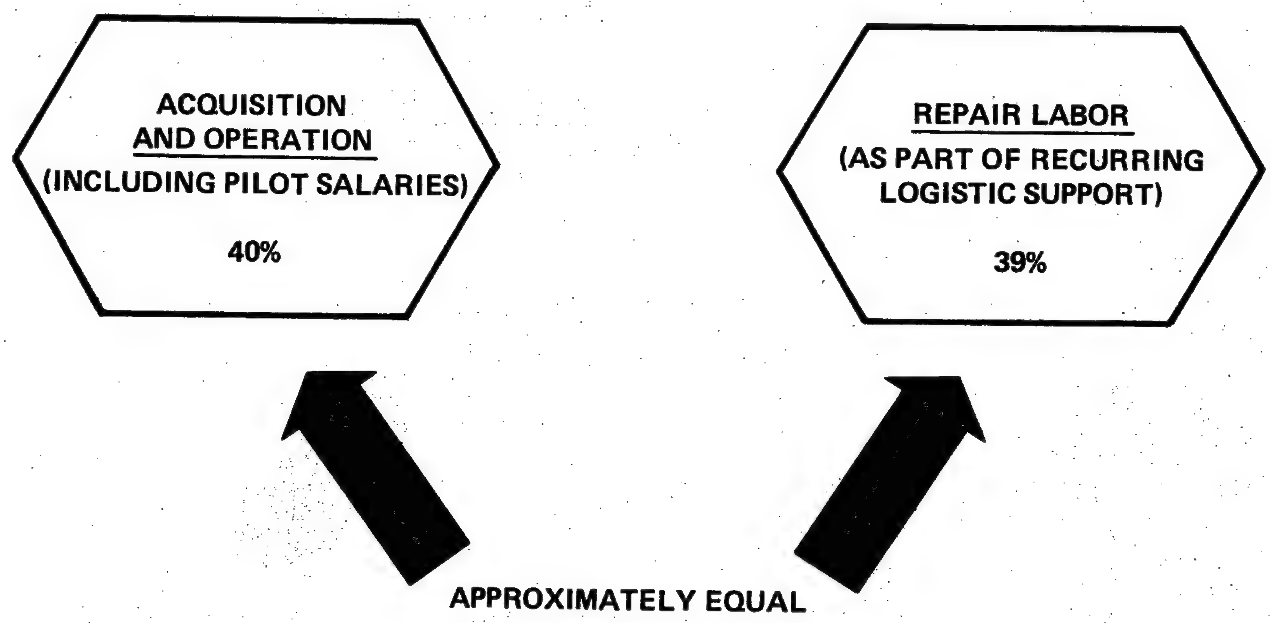

FIGURE 1. ASSESSMENT OF LIFE CYCLE COST "DRIVERS"
ONE CASE: A-7D WEAPON SYSTEM. (ADAPTED FROM FIORELLO, 1975)

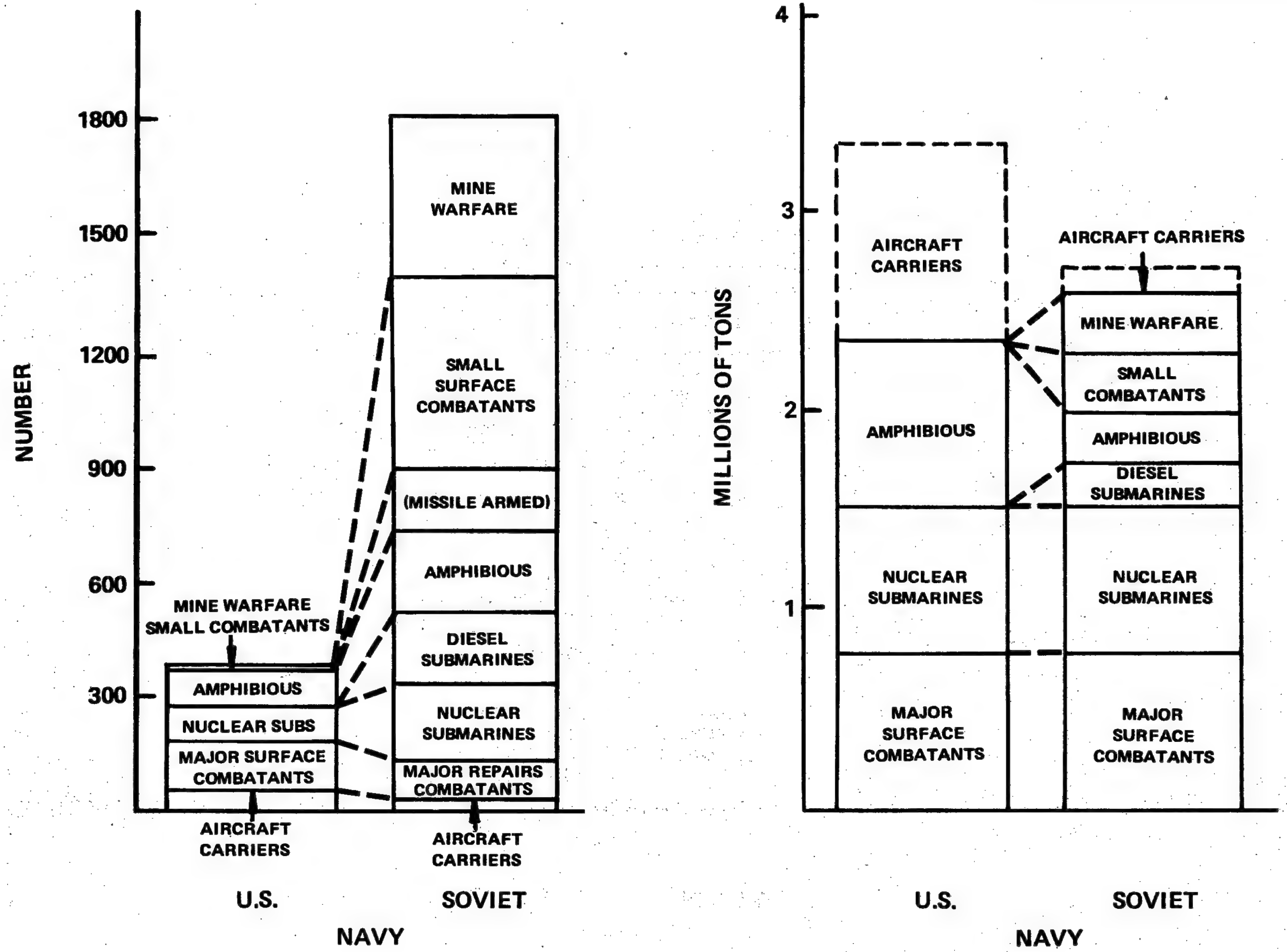

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FIGURE 2. COMPARISON OF NUMBERS AND TONNAGES OF THE VARIOUS SHIP CATEGORIES IN THE U.S. AND SOVIET NAVIES. (ADAPTED FROM NAVSO, P-3560, 1978)

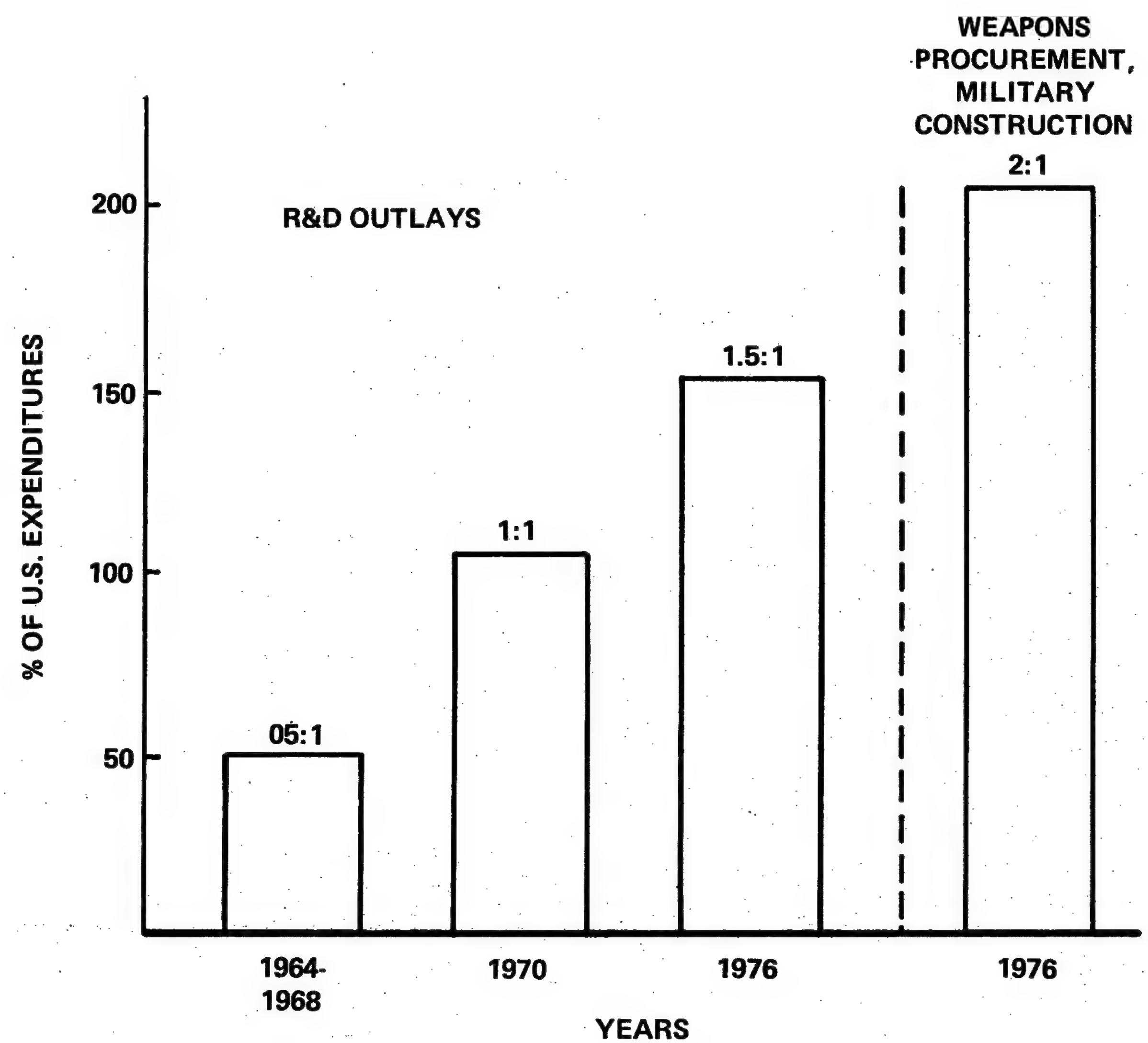

FIGURE 3. SOVIET RESEARCH AND DEVELOPMENT EXPENDITURES, EXPRESSED AS A PERCENTAGE OF U.S. RESEARCH AND DEVELOPMENT EXPENDITURES, AND RESULTING RELATIVE SPENDING FOR WEAPONS PROCUREMENT AND MILITARY CONSTRUCTION. (ADAPTED FROM HEAD, 1978)

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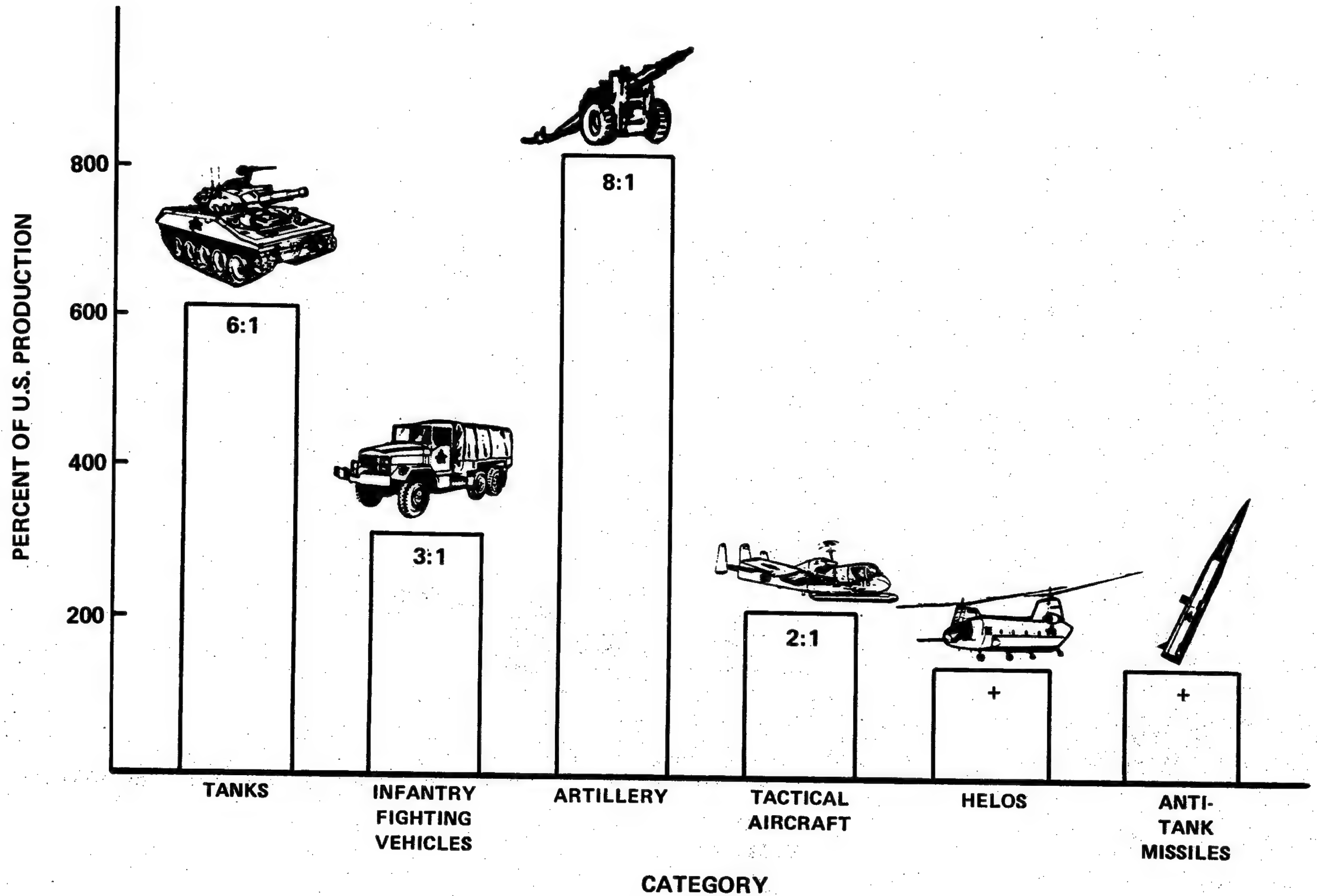

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FIGURE 4. CURRENT SOVIET PRODUCTION OF SIX CATEGORIES OF MILITARY EQUIPMENT, EXPRESSED AS A PERCENTAGE OF CURRENT U.S. PRODUCTION IN THOSE CATEGORIES (ADAPTED FROM HEAD, 1978)

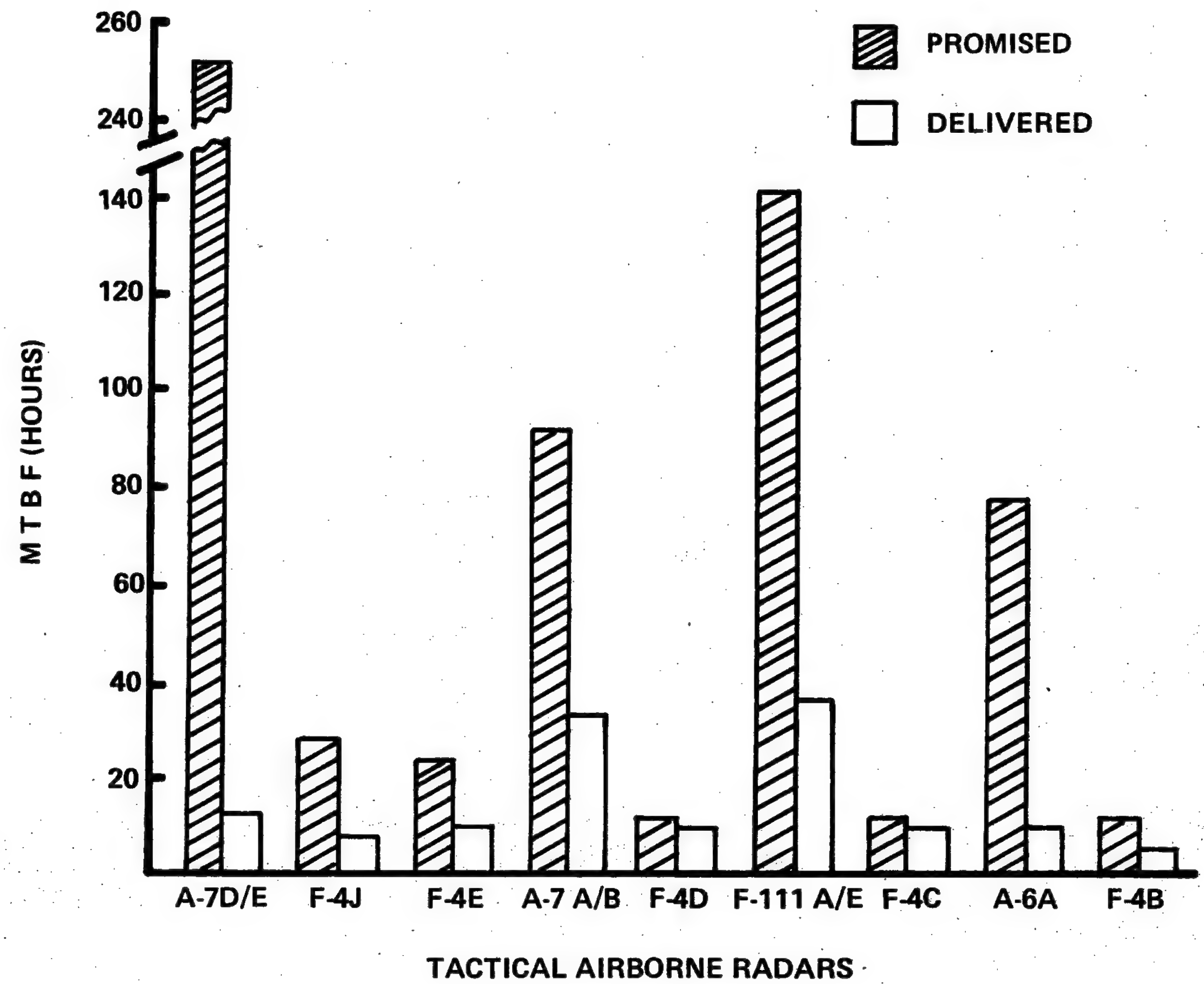

FIGURE 5. RELIABILITY PROMISED IN THE SPECIFICATIONS AND OPERATIONAL RELIABILITY ACTUALLY DELIVERED FOR SEVERAL TACTICAL AIRBORNE RADAR SYSTEMS. (ADAPTED FROM PYATT, 1972)

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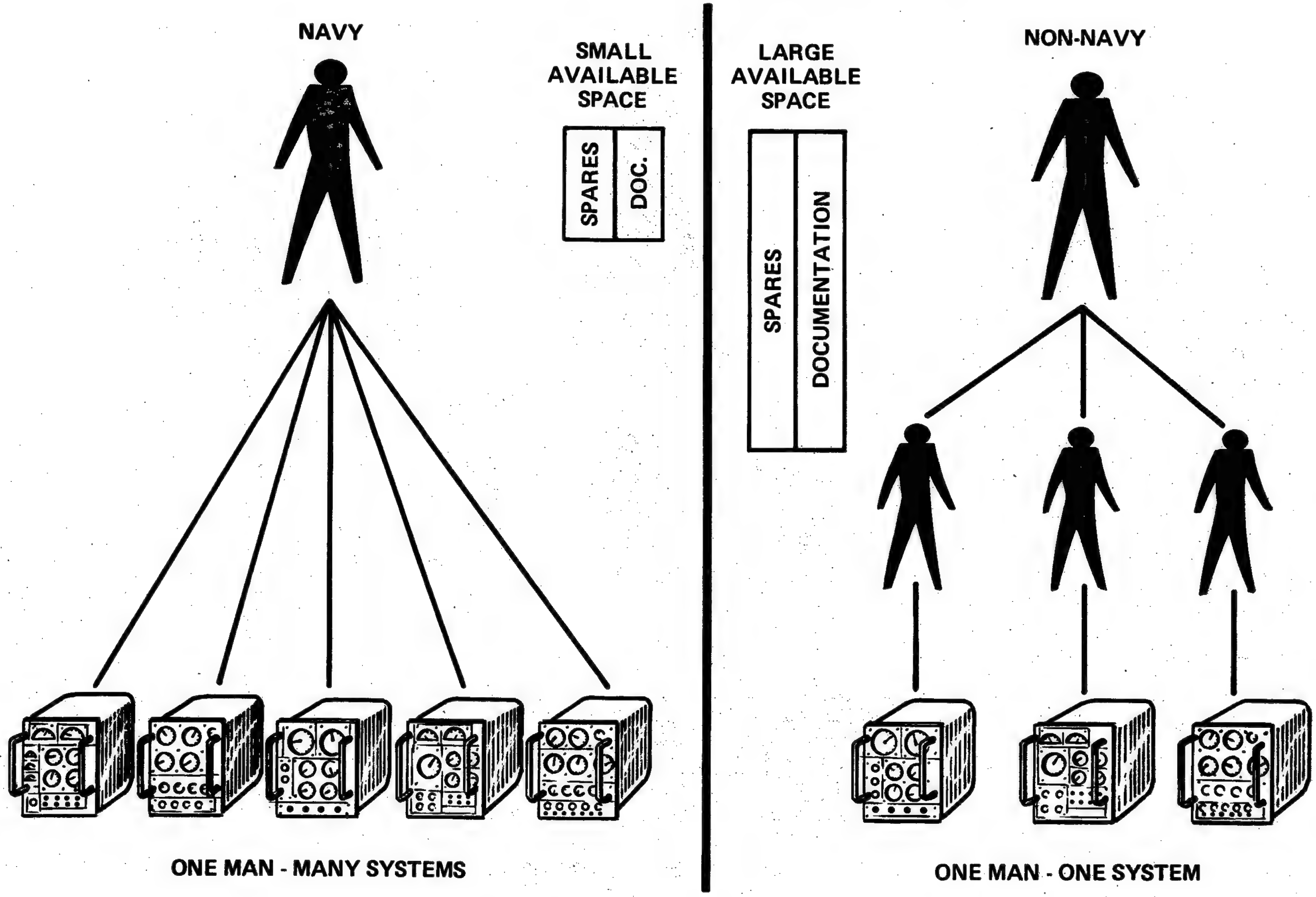

FIGURE 6. THE NAVY SPACE/RESUPPLY PROBLEM. UNLIKE NON-NAVY COUNTERPARTS, NAVY TECHNICIANS OFTEN HAVE RESPONSIBILITY FOR SEVERAL SYSTEMS, WITH VERY LIMITED SPACE FOR STORAGE OF SPARES AND DOCUMENTATION.

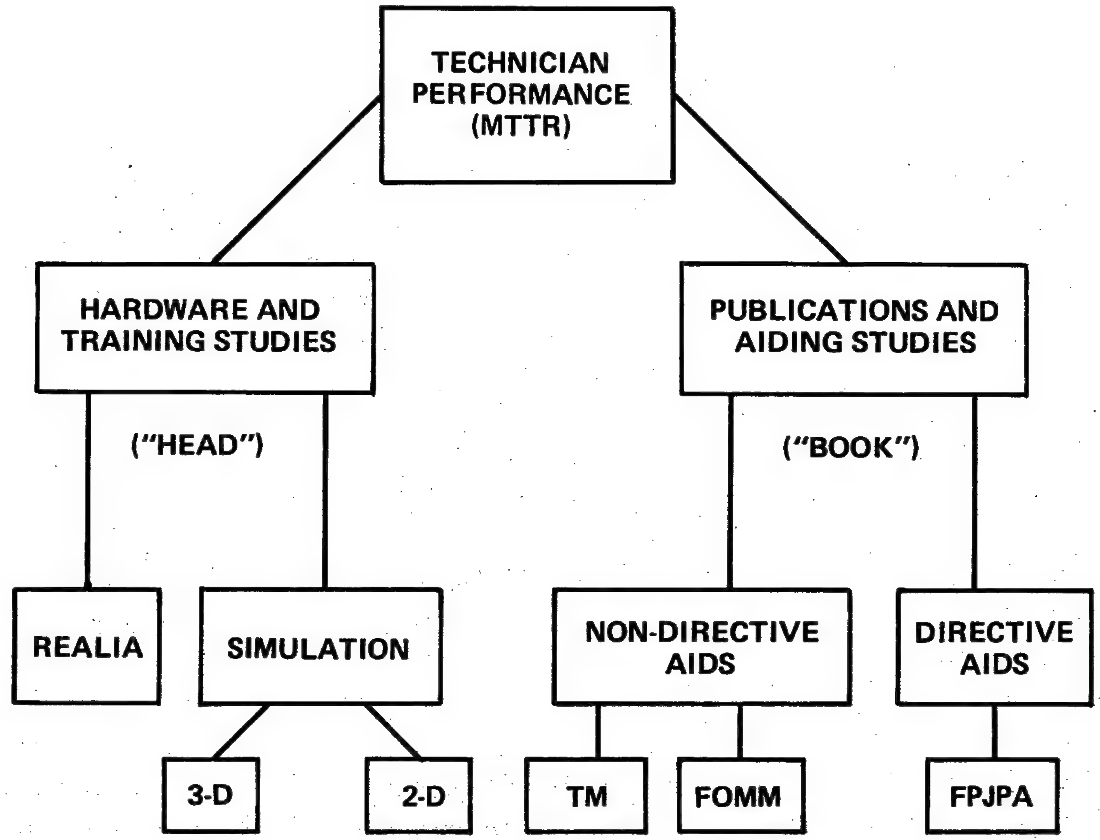

FIGURE 7. SUMMARY OF AVAILABLE MEDIA FROM THE HARDWARE AND PUBLICATION WORLDS, AS DERIVED FROM STUDIES IN IMPROVEMENT OF TECHNICIAN PERFORMANCE.

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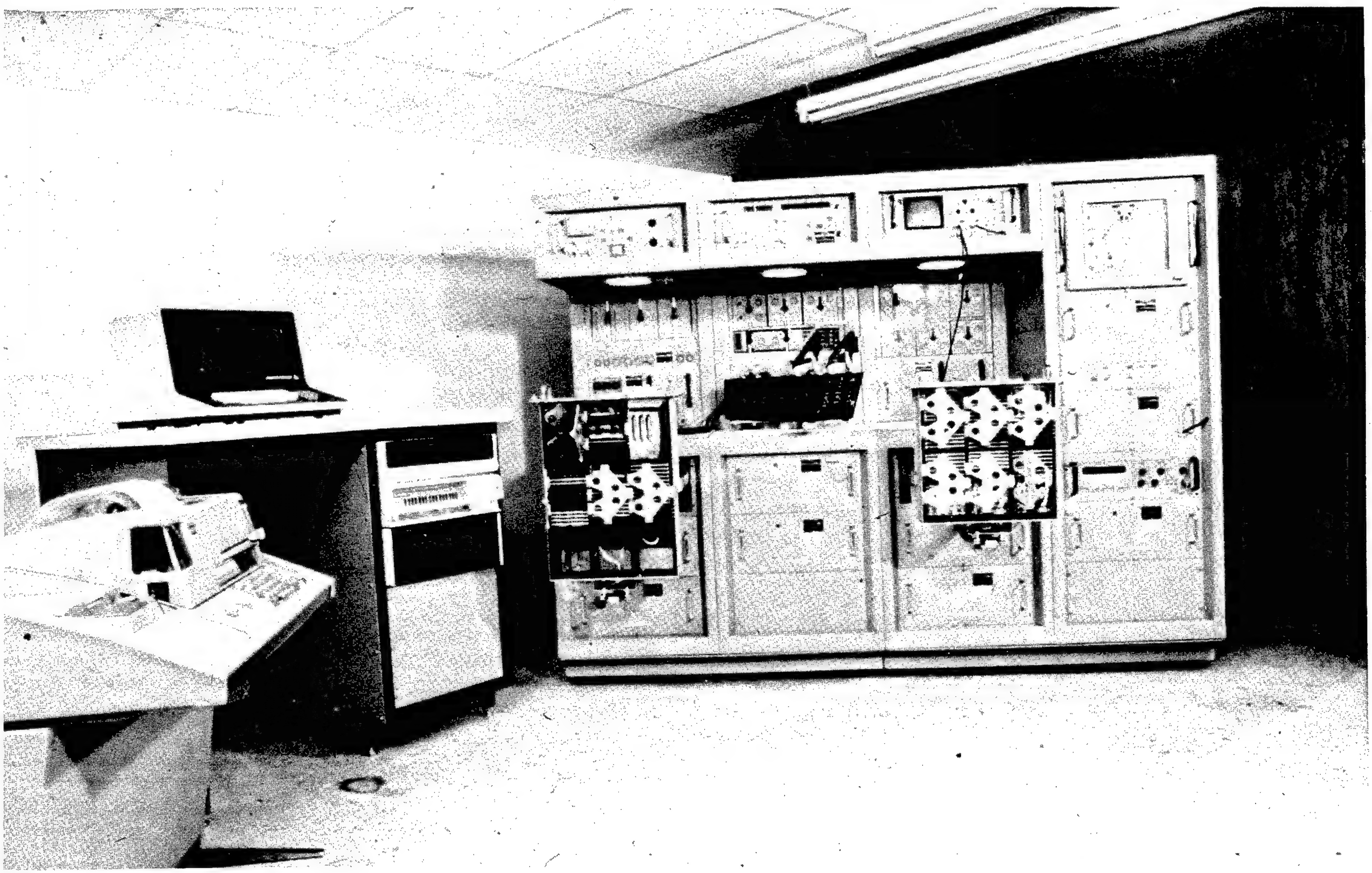

FIGURE 8. HEAD-UP DISPLAY SET TEST SET SIMULATOR DEVELOPED THROUGH NAVTRAEQUIPCEN HUMAN FACTORS LABORATORY.

PREDICTION OF SYSTEM PERFORMANCE AND COST EFFECTIVENESS USING HUMAN OPERATOR MODELING

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Prediction of System Performance and Cost Effectiveness Using Human Operator Modeling

Abstract

Development of modern air weapons systems must respond to constantly changing threat conditions. Continual increases in system performance must be achieved through new designs or through updating of existing equipment. Most approaches to system improvement involve avionics hardware/software changes to enhance data processing and display or improve accuracy and quality of system inputs. As interdependence of system components becomes more intricate, the impact of proposed changes can no longer be directly estimated as an increment to current performance. The ability of the operator to use new capabilities must be considered in the prediction of overall system effectiveness. Inappropriate automation of system functions may actually result in performance decrements if not matched against operator requirements throughout the mission timeline. Sensor data refinements will not change performance if they exceed the precision which an operator can use to perform his functions. Also of importance in evaluating a proposed system is the life-cycle cost associated with its implementation. Alternatives may differ considerably in cost to accomplish the same objective, and would correspondingly vary in cost effectiveness. Proposed designs must be examined both for changes to current or baseline performance and for associated increases in baseline cost.

Previous approaches to predicting system effectiveness have focused on simulation of hardware/software components without considering an operator's ability or inability to capitalize on improved features. The approach described here, Operator Interface Cost Effectiveness Analysis (OICEA), integrated major avionics system variables into a single cohesive model which simulates hardware and software functions and the performance of an operator interacting with these components, using a model called the Human Operator Simulator (HOS). Alternative systems are compared with respect to predicted effectiveness when used by an operator, and costing techniques provide estimates of cost effectiveness for each approach. The technique allows for system variation of key factors impacting effectiveness, including equipment and human reliability, scenario features and operator capabilities. This paper describes the OICEA methodology, documents and applicaction to a fixed-wing antisubmarine warfare mission, and illustrates the variation of system and operator parameters during evaluation of alternative designs.

Introduction

Development and modification of modern air weapon systems are conducted in an environment of constantly changing and evolving threat conditions. In response to a changing threat environemnt, new systems must be initiated and existing systems updated to produce systems that will be more effective in countering both known and presumed threats. With the increasing costs of modern systems and the increasing need to demonstrate return on investment, techniques have been developed to estimate the impact on system performance of proposed new designs and updates. These predictions of future effectiveness, usually obtained through computer modeling of all or part of the system, have involved the implicit assumption that increasing system capabilities will yield a direct and comparable increase in system performance. However, experience with the use of new and updated systems in the fleet has indicated that this assumption is not always tenable. One possible reason for this is that estimates of system performance from conventional hardware and software models overlook an important system component -- the operator. In particular, human limitations may impose a limiting factor on the utilization of system improvements.

System enhancements usually involve either new hardware or new software that increase the degree and quality of automation, or improvements in the accuracy and sensitivity of sensor information and other system input data. Conventional methods of performance prediction have either ignored the operator or have used simple transfer function representations, without an adequate understanding, of the limits within which these functions are applicable. As systems have increased in complexity, it is no longer adequate to assume that automation or computerizing the wrong aspects of the job may, in fact, have the opposite effect. We can no longer assume that by giving the operator more sophisticated data, system performance will automatically be improved. Additional or more refined sensor data, for example, will not improve performance if it is received during periods of heavy operator loading or if the data exceeds the precision which the operator needs to perform a given function. Proposed system changes must therefore be evaluated by considering how well an operator can make use of the new capabilities provided by the proposed changes. Evaluation techniques that do not consider this factor in their estimates will be in error; as operator loading approaches saturation, such estimates will become wildly optimistic.

Designers of current and future weapon systems must cope with several harsh realities that constrain available design options. First, funds for development and deployment of systems are becoming limited; pressures are mounting for more cost-effective utilization of fiscal

resources. Design decisions must be made on the basis of maximum contribution to the defense mission for each dollar invested. The most effective design is the one which meets mission requirements at the minimum cost.

A second major constraint that is being recognized more and more is that the human is no longer a low-cost component of systems, nor is manpower available in unlimited quantities with all required skills. The effective use of available manpower must be a primary consideration in the selection of design options; new systems must make effective compromises between the use of man and use of equipment to accomplish system functions, with cost-effectiveness as a major criterion for choosing between design alternatives.

The critical role of operator capabilities in limiting or enhancing systems effectiveness, together with the fiscal and manpower constraints discussed above, indicate the need for a method that will predict with reasonable accuracy what system performance will be for a particular configuration and that will provide realistic estimates of how that configuration will perform when manned by operators of varying ability. Such information, when combined with appropriate cost data, would enable a choice to made between alternative design configurations on the basis of expected performance relative to expected cost.

The work described in this paper represents an initial effort to develop such cost-effectiveness prediction methodology. The approach, called Operator Interface Cost Effectiveness Analysis (OICEA), uses the Human Operator Simulator (HOS) Model (1, 2), developed for evaluating system operability during early system design. The following sections describe the OICEA methodology, its rationale, and the results obtained by applying it to a fixed-wing antisubmarine warfare mission.

APPROACH

Rationale

Differing system configurations, proposed in response to the need for improved system performance, may vary widely in effectiveness in their ultimate application but may appear to be virtually indistinguishable in potential value during early development stages. Since it is normally prohibitively expensive to develop each alternative to the hardware simulator or prototype stage in order to obtain an estimate of its potential worth, there is a need for methodologies that can be used early in the system design process to help decide which alternatives should continue under development. Digital computer modeling has been a traditional and typically effective method for

making such forecasts under such conditions. OICEA adds to the concept of equipment modeling by combining it with the ability to simulate the functioning of an operator within the system and by applying standard costing techniques to derive projected life cycle costs. From these data, alternatives can be compared to one another and to existing systems capability on the basis of cost effectiveness.

Any model that is to be used to perform such an evaluation must satisfy several criteria. First, it must be *integrative*. It must be able to simulate the hardware, software, and operator system components within a single conceptual framework, along with any external data sources (sensor data returns, communications, etc.). Second, the model must be *flexible*; it must be able to accommodate without any major revisions virtually any class of manned system or subsystem and provide for straightforward modification of system characteristics without extensive reprogramming. Third, it must be *sensitive* to relatively subtle differences in configuration performance. This presupposes a level of detail in the model consistent with the use of task or subtask level task-analytic data for operators and input/output characteristics for equipment. The sensitivity criterion also demands that the model be dynamic -- reallocating its task priorities in accordance with performance influences which may be exclusively timeline-dependent. Fourth, the model must be *parametric*. Many of the quantities which describe operator capabilities and performance characteristics of equipment are not fixed values, but can vary both between and within operators and between and within hardware/software configurations. It may be of great value to iterate simulations with different values of potential key parameters, both to determine which of these particular parameters are important in this specific simulation and to identify parameter values that provide best performance. Varying such quantities as software processing time for a sensor return, detection range or resolution for radar, and operator recall time for procedures can yield valuable information about design and training questions as well as estimating system effectiveness. Fifth, the model must be able to produce specific *quantitative* measures of system performance. There are, for any system, numerous ways of deriving numbers which reflect performance. The combination of measures into a single global assessment of performance must eventually entail obtaining explicit judgments of worth or utility for each of these effectiveness measures. The model, however, must enable the estimation of separate performance indices that are specifically quantifiable and mission-relevant; such measures, as time to perform a mission, ordnance or stores expended, number of correct ship/aircraft identifications, targets processed or probable kills are all potential numerical reflections of system success. While the appropriate measures will change from one system to another, effectiveness indices should be readily obtainable from routine model outputs.

The Human Operator Simulator

HOS is a digital computer program designed to simulate the complex interactions between man and equipment by modeling both the operating characteristics of the machine and the perceptual, cognitive and motor functions of the operator. HOS is a "generalized operator." It becomes a specific operator in a specific situation when it is provided with descriptions of equipment to be used and procedures to be followed. These procedural instructions are written in a simplified English-like computer language called HOPROC -- the Human Operator Procedures Language.

HOS differs from other models of operator functioning in that times for task execution are not supplied by an analyst or drawn from sample time distributions. Instead, HOS generates task performance data in accordance with detailed micromodels of human performance built into the HOS system. The HOS operator is capable of performing seven "primitive functions" -- obtaining information, remembering information, performing mental calculations, making decisions, moving a body part, manipulating a control, and relaxing. Every action that the HOS operator performs is a combination of one or more of these primitive functions. Internal decision rules within HOS will automatically determine the function combinations that make up a task, determine the sequence in which tasks are performed, and calculate the time required to complete them. The HOS operator is goal-oriented; that is, he will perform actions necessary to accomplish a task, but will omit actions that have become unnecessary at some point in time due to events elsewhere in the simulation.

Procedures and tasks to be performed by the operator are coded in HOPROC and broken down into appropriate micromodel calls by HOS, using a set of internal algorithms. Each of the micromodels assesses "time charges" against the mission in accordance with its own simulation rules derived from human performance data and special experimentation. Procedures are tied to one another through a series of multiplexed control routines and through a "banker" which collects time charges and records system activities for later analysis. The detailed analysis of system events is performed by a routine called HODAC (Human Operator Data Analyzer and Collater), which provides information on what the operator is doing and what equipment is involved at any instant in time during the simulation. HODAC summaries can be used to obtain an exact breakdown of how an operator spent his time during a mission, which sequences he executes and how often, the frequency and total time spent in accessing each control and display, along with other summary reports.

HOPROC, in addition to being used for coding operator procedures, is also used for coding procedures which simulate the system hardware and software components. Procedures or tasks to be performed by equipment are coded in exactly the same way as operator procedures; transfer functions or mathematical expressions of hardware functioning may be represented either in HOPROC or in FORTRAN which is a subset of HOPROC.

HOS has several sophisticated features that make it particularly applicable to the simulation of complex missions. For example, the HOS operator has extensive decision making capabilities expressed in the form of formal strategies or decision rules supplied by the analyst that may employ IF and branching logic and that may be dependent on system status at the time the decision must be made. The HOS operator has internal prioritization algorithms that it uses to determine what to do next. In making decisions about what procedure to work on, HOS is guided by two factors -- the original procedure priority (set by the analyst) and a modification to that priority which changes with time since that procedure was last executed. For procedures which involve reading displays, control manipulation, or instrument monitoring, priorities are also modified by a factor called "internal limits," which specifies the degree of precision required for that operation. Procedures with small internal limits must be executed more often, and priorities are changed accordingly. Based on all these factors, computed priorities are compared and the most critical procedure is executed. The priority queuing model and internal limits concept are defined in detail in reference (3).

The ability to vary the characteristics of the HOS operator has been referred to earlier. In running the HOS model, a number of parameters describing operator characteristics must be provided to the simulation at object time. The default values of these parameters are chosen to represent a trained operator of "average" capabilities who will perform assigned tasks with little or no chance for error *unless* that error is specifically introduced and controlled by the analyst. (HOS will not make procedural errors unless told to do so, but can forget information or misread a number). This power to control the characteristics of the operator provides a ready method of determining the range of operator abilities for which a system is suitable.

The HOS system has been used to simulate a variety of relatively simple tasks such as reach performance, multiple dial reading and mail sorting (4). It has been applied to assessment of operator workload in a dual task situation (5) and for simulation of a complex operational mission, that of the Air Tactical Officer in the LAMPS antisubmarine helicopter (3). The brief description of HOS in this paper is supplemented by the HOS Study Guide (6) and by detailed micromodel

descriptions in reference (3). Useful analyses which discuss HOS in the context of other operator models are contained in Pew, Baron, Feehrer, and Miller (7), and in Greening (8).

Operator Interface Cost Effectiveness Analysis

The approach to system evaluation described in this paper is not a new model. It is rather a way of using a model to organize and answer questions about new systems or alternative designs. The goal is to provide the best possible projections of the performance of those alternatives under the range of conditions likely to be encountered in fleet use.

Systems are rarely manned by perfect operators. While it is important to know the performance potential of a system if operators were capable of handling any task conceived by a system designer, it is much more critical to understand the probable performance given a typical operator with human limitations. It is not uncommon for substantial research and development costs to be invested in a system which performs a mission more poorly than a system already available. Some new systems achieve distinct improvements in performance, but only with an unacceptable level of operating and support costs.

It is never the intent of designers to reduce performance or increase costs beyond the acceptable level. Frequently, however, these criteria are not applied in choosing among the various available ways of obtaining a desired improvement in system performance. The premise of the OICEA approach is to make such considerations explicit by the deliberate comparison of alternatives to a baseline performance level and a baseline cost. This approach, briefly stated, is the systematic application of digital simulation to derive cost/performance data as early as possible in the design cycle. Generally, this will involve: (a) simulating a baseline system; (b) simulating one or more system alternatives; (c) obtaining appropriate performance measures for baseline and alternatives; (d) obtaining baseline and alternative cost data; and (e) generating cost/benefit tradeoffs based on these data. The flexibility offered by modeling allows performance estimates for a variety of scenarios and tactics, under degraded mode conditions and with varied operator procedures or tactical doctrine. To achieve such a breadth of comparison using prototypes, dynamic simulators or functioning mockups would require excessively heavy investments of time and dollars, and results would be too late to impact on system selection. It is the capability for early identification of most effective directions in development that makes the OICEA approach most promising.

OICEA APPLICATION

Objective

The primary goal of this initial application of the OICEA methodology was to determine if the technique, applied to existing systems with known problems, could identify those problems and provide objective data on the type that might have led to correction had the data been available during design. The Sensor Station 3 (SS-3) operator workstation of the P-3C antisubmarine patrol aircraft was selected for simulation for purposes of this demonstration. The SS-3 station was chosen primarily because (a) three distinct configurations of the SS-3 already exist in the fleet, (b) extensive documentation on the system is available, and (c) it is known that this station has chronic operator overload problems during certain missions and it was desirable to compare these problems with those identified from simulation output.

Descriptions of the simulation that follow are considerably abstracted and abridged. Reference (9) contains full data on the mission, scenario and operator tasks, and on specific equipment details omitted below.

Mission and Scenario

The mission to be flown was a surface search of an anchorage area off the coast of a Mediterranean third-world nation. The area of interest was 10x10 nautical miles (nm) square. Primary objective of the anchorage mission was to confirm the presence or absence of a specific ship within the area by acquiring Electronics Support Measures (ESM) data from a target matching the signature of at least one of the emitters known to be on that ship, followed by visual confirmation, and the acquisition of Forward-Looking-Infrared (FLIR) pictures (if so equipped) of all contacts not positively identified as either neutral or friendly. The tactical constraints were that (a) flight within 12 nm of the coastline was prohibited; (b) total time in the anchorage area was to be minimized, (c) a single direct overflight tactic was to be employed, (d) the aircraft would maintain 2000 feet and 180 knots within the anchorage area, and (e) vessels not in the anchorage area were to be ignored after their location was determined.

Figure 1 shows the layout of the anchorage area with locations of targets and emitters. There are 37 total emitters of which six were targets of interest within the anchorage. Emitters varied in duty cycle and in period of emission. The aircraft entered from the initial

point (IP) to the north and was to fly from target to target, in turn, until all targets in the area of interest had been examined.

Configurations and Tactics

Four equipment configurations of the SS-3 station were employed:

(1) The Baseline configuration was the standard P-3C without FLIR.

(2) The Non-Apriori configuration was the Baseline aircraft with the apriori filtering capability of the system rendered inoperative. The Apriori table performs preanalysis of ESM contacts and identifies those whose emissions are characteristic of particular target classes. This version of the simulation was run in order to examine the behavior of the model in a degraded-mode of operation.

(3) Baseline + FLIR. This configuration was the same as Baseline with the addition of a FLIR system controlled by means of a joystick control.

(4) Update. This configuration corresponded to the P-3C Update II with an Infrared Detection System (IRDS), essentially a FLIR system with automated tracking capability.

Tactics varied among configurations as a function of onboard equipment. Specific tactics used for each configuration were developed with the assistance of, and were approved by, fleet SS-3 operators with recent experience in Mediterranean anchorage missions. The tasks set for the simulated operator executing these tactics were extremely complex. Figure 2 gives a general listing of the classes of these operator tasks.

System Performance Measures

An anchorage mission is primarily an intelligence gathering exercise, where the information to be obtained includes ESM data and FLIR pictures, in addition to the basic requirement of identifying and locating targets in the anchorage area. Balanced against the objective of maximizing information was the requirement that minimum time be spent in the anchorage area. This leads to two classes of performance measures for this mission -- *Amount of Information Gathered*, in this case Emitters Correctly Identified (EI) and FLIR Pictures obtained (FP), and *Time to Complete Mission*. Both of these types of measures are dependent on the tactical situation and on the locations

of targets and emitters. Thus, the performance measures obtained for a single simulation must be considered as relative performance indicators; to broaden the generalizations from these measures, it was necessary to vary some simulation characteristics.

Sensitivity Analyses

The discussion above pointed out that the parameters which might influence simulation outcomes in a model must be able to be varied and controlled. The relative nature of outcomes noted in the previous sections can be overcome by systematically changing key parameters or mission characteristics and examining the robustness of the findings to such changes. This procedure is analogous to the concept of sensitivity analysis common to model developments, in which one determines the range of values for which an equation or algorithm may be valid, or examines the sensitivity of a modeled phenomenon to variations in one or more model parameters.

This procedure of exploring the impact of changing characteristics on simulation outcomes is especially critical for diagnosing the reasons for differences in systems performance. If, for example, changes in operator capabilities produce little change in the relative rankings of alternative configurations, it would suggest that differences between configurations are reflecting straightforward equipment differences, unmodified by the limitations of the operator. On the other hand, if such operator variations should reverse the performance rankings of configurations, a way of reducing operator workload by redesign or by specific crew training requirements might be sought.

As a follow-on to the studies described in reference (9), a limited sensitivity analysis was performed. Using the same scenario and mission as in the preceding study, the approach path to the anchorage area was changed from north to west, display reading by the operator was degraded to introduce possible errors in display resolution, and operator manipulation time for controls was increased slightly.

RESULTS AND DISCUSSION

Results presented in this section are primarily summaries of the detailed analyses performed on the output of the four simulations. In-depth descriptions of results, including minute-by-minute activity timelines, specific aircraft flight paths and operator activity analyses by procedure are given in reference (9), which also contains the complete HOPROC coding and HODAC output.

Performance Measures

Figure 3 shows a summary of performance for each of the four system configurations. Time to Complete Mission varies dramatically across configurations. As the figure indicates, the Baseline required 32 minutes to process and acquire 89 percent of the Emitters of Interest (EI). The Baseline version with the apriori table inactive processed about 20 percent fewer emitters and required one more minute to complete the mission. Neither of these versions was equipped with FLIR. Most striking is the comparison of time and effectiveness for the Baseline, Baseline + FLIR, and Update versions. When the manual FLIR is added to Baseline in order to permit FLIR acquisition of data, severe degradation of ESM effectiveness occurs, with a drop in emitter acquisition from 89 percent to 67 percent, and a minimal performance in FLIR, with less than 10 percent (1 of 12) of the possible FLIR pictures actually acquired. Thus, the manual FLIR addition not only fails to provide FLIR capability as intended, but interferes strongly with the ESM tasks. This is in distinct contrast to the Update version, in which the automated FLIR improves performance on all measures, accomplishing 100 percent success in both ESM processing and FLIR acquisition, at a savings of 8 minutes in time over the Baseline.

Analyses of operator activity show that the ineffective performance of Baseline + FLIR is due primarily to the characteristics of the FLIR manual control. A control slew rate of 1.7 deg/sec, too slow for the operator to overcome lag time in response to aircraft movement, was identified by the HODAC analysis. This problem could have been overcome by a straightforward control redesign had the deficiency been identified prior to fleet introduction. The capability to detect and diagnose problems at this level of detail from a simulated mission indicates a distinct strength of the HOS and OICEA approach.

Cost

Cost data used in this preliminary study reflect only Operating and Support (O&S) costs, due in large part to the difficulty of obtaining accurate data on research and development costs after a system is completed. For purposes of this demonstration, O&S costs are satisfactory, although they tend to be relatively insensitive to configuration differences, since the major components of O&S costs are only slightly affected by changes in measures other than time. Further, the O&S costs used here do not reflect large differences due to maintenance cost variations as would generally be the case for systems with more variability in the nature of equipment components than those evaluated in this study.

Figure 4 shows the standard O&S formula for flight hour costs and the cost/hour determined for the Baseline P-3C. Figure 5 gives, for each configuration, the on-station flight time, estimated O&S costs per flight hour, and the On-Station Cost, a summary value which indicates the total cost to perform one mission from the initial point to area departure. The most striking feature is the change in mission cost from $1,961 for the Baseline to $1,510 for the Update, a decrease of 23 percent accompanied by the sharp performance improvement already described.

Relative Cost-Effectiveness

Two factors discussed earlier were the relative nature of performance measures and the necessity for establishing a baseline of current cost-effectiveness against which proposed alternative solutions could be compared. One of the objectives of OICEA is to provide guidance to designers and decision makers about the most fruitful lines of development to solve a requirement for increased system performance. One method of providing this guidance is the concept of "acceptance regions" demonstrated in Figure 6. This figure displays data from Figures 4 and 5 in a format which highlights the relative standings of the configurations examined. In order for a proposed solution to be considered, it should fall in or near the acceptance region. The size and location of this region will be governed by the cost-effectiveness of current capability and by other factors, such as the importance placed on cost as an evaluation factor. Cost could be of decreased weighting in the decision process if the threat responded to was sufficiently critical.

Figure 6 deals only with performance on ESM processing. A similar figure could, of course, be constructed for FLIR performance. It should be noted that the use of On-Station Cost is a convenient way of incorporating one performance measure, time, into the display of cost-effectiveness for another measure. The format suggested by the figure is only an example of presenting cost/performance information. If research and development costs had been available, presentation of data would have been considerably more complicated.

Effects of Varying Utilities

Simulation of the anchorage mission produced three measures of system effectiveness -- Time, %EI, and %FP. These measures, particularly the latter two, are mission-specific and partly dependent on the specific tactical environment. In the analysis, they have been treated as separate indices of performance. It would be more desirable when evaluating cost/performance to deal with a single global measure of performance which aggregates all possible measures of

success. To do this, it would be necessary to specify numerically what each measure is worth in the total context of satisfying mission requirements. These indications of worth are the *utilities* of each performance measure. Weighting performance measures by their judged utilities can yield the desired global measure.

Obtaining utilities is not simple. Whereas a properly defined mission requirement should identify what performance is demanded and what the associated utilities are as an integral part of the requirement statement, such data are generally not provided. It may be possible in specific cases to obtain utility judgments from policy makers, but this is not a common practice at present.

Another way to examine the effect of utility weighting is to develop "boundary solutions" to each acceptance region. This is done by systematically varying utilities through their probable ranges and examining the changing locations of system alternatives relative to the acceptance regions. Although data from this study is not particularly suited to such manipulation due to the clearcut superiority of one version, an example can be given for the Baseline + FLIR and Update versions. If the objective is to minimize On-Station Cost relative to total performance, and if %EI and %FP had utilities ranging from 90/10 (EI is worth nine time as much as FLIR performance), to 10/90 (FLIR nine times the value of EI), there is *no* combination of utility weights which will result in Update being judged less effective. Thus, the Update configuration is superior regardless of the "true" utility and the boundary solutions for acceptance regions are the same for all utility combinations. It is obviously easy to conceive of situations in which decisions would not be so clearcut given a range of utilities. The concept of determining boundaries for which decisions on relative cost-effectiveness would be unchanged is applicable to virtually any multiple performance measure problem.

Effects of Varying Parameters

As previously noted, several of the characteristics of the original simulation have been modified in a separate series of sensitivity analyses. These analyses sought to determine the stability of the initial simulations to changes in the tactical situation, display resolution, and operator manual response times. A secondary goal was to explore the diagnostic value of these changes for pointing out areas in which realistic design options could be tested at an equipment subcomponent level. Each of the three alterations defined above will be repeated for each of the four SS-3 configurations and results compared to those from the original simulations. At the time

of this report, only part of these analyses have been completed. Partial results have suggested that valuable information may be obtained by this process of parameter variation.

When a HOS simulation is run, a value is input to the model which describes the amount of time required by an operator to decide if he can retrieve a given piece of information from memory. This value is analogous to memory cycle time for a computer, and estimates the time for one iteration by the operator through his "memory store." This value has been used by HOS analysts to represent the degree of procedural familiarity possessed by a simulated operator. The presumption of an increased "cycle time" is that the operator with less training will be able to remember procedures and will execute them properly, but will take longer to recall the information needed for each procedural step. In the development of the original Baseline simulation, this parameter was varied over a range from the default value (.04 seconds) to twice that number. The findings were somewhat unexpected. The time to recall information has a distinct effect on how an operator allocated his time across procedures, but had little or no effect on overall system performance. Demands of the system were apparently such that information recall time was a minor element compared to task execution time. A tentative interpretation of these findings for the Baseline simulation is that in Baseline information changed at such a rate that the need for an operator to be able to retain a variety of types of information "in his head" from moment to moment was not important as long as he was adequately trained in how to use the system to obtain the data when he needed it.

In another variation on the Baseline simulation, the resolution available to the operator from the radar display was degraded to reduce the positional accuracy with which a contact could be located. When the operator wishes to identify to the system which of several contacts he wants to enter into the onboard computer, he manipulates a trackball which moves the position of a small circle (the hook) on the display. When the contact is encircled by the hook, it is entered into the onboard computer system's memory by a key depression. The operator controls the area covered by the display, with radius options of 2 to 1024 mni in powers of two. One change to the Baseline configuration provided for a resolution uncertainty of 2 percent of the distance between points on the display. Given what would appear to be a reasonable error tolerance, the simulated operator was unable to complete the HOOK and ENTER TARGET tasks. He spent large amounts of time trying to coordinate the trackball movements of the hook with the estimated location of the contact. The 2 percent error in resolution was too great for satisfactory task performance. In a second modification, resolution was changed to provide for a tolerance of 0.25 percent of the display radius. Given this error potential,

operator (and system) performance was not detectably different from the performance obtained under conditions of perfect resolution in the original simulation.

The examples above are illustrative of the level of detail that can be achieved by controlled variation of HOS simulations. Information such as display resolution or sensor accuracy required by the operator to do his job could be of considerable utility in determining the equipment characteristics of systems still in the design stages. Similar analyses are being conducted for variations on the other factors previously discussed. Outcomes of these simulations will be reported in reference (10).

CONCLUSIONS

Work described in this paper was initiated in response to the observation that system modifications and designs, introduced to improve total system performance, frequently had no effect or an adverse impact on that performance. The objective of these initial studies was to determine if the OICEA approach could predict such performance decrements and uneconomical configurations. This objective has been clearly achieved, although substantial work is still required, particularly in the costing area. The Baseline + FLIR simulation demonstrates that the addition of a FLIR sensor seriously degraded ESM performance with an almost negligible increment in the amount of other information obtained. The addition of the FLIR sensor was not economically justifiable. The performance achieved by the Update version, conversely, showed a substantial economic justification.

These conclusions and the accuracy of the simulations themselves are substantiated by fleet reports on difficulties experienced by SS-3 operators. Fleet operators are unable to perform manual FLIR tracking and ESM processing simultaneously. One of the other operators must be called on to assume one function while the SS-3 operator does the other. This difficulty and its root causes are clearly identified by the simulation.

Preliminary methods of analysis and display of cost-effectiveness data suggest that the acceptance regions and boundary solutions for utilities derivable from model outputs can be of great value as design and decision tools. Results of sensitivity analyses suggest a considerable power for systematically exploring mission and operator parameters in determining the robustness of simulation output to the idiosyncrasies of a single simulation.

The rationale for OICEA is to determine whether specific cost and performance questions which should be raised about all new designs and

modifications can be answered through the use of computer modeling. Our results, at least for the mission and configurations considered in these studies, clearly supports this approach to system design.

Biographical Sketch

Commander Norman E. Lane

Since 1975, CDR Lane has been program manager for advanced development in human factors engineering at the Naval Air Development Center. He entered the Navy in 1963 after receiving an M.A. in Industrial Psychology from the University of Florida and was designated as an Aerospace Experimental Psychologist in 1964. He has had previous assignments at the Naval Aerospace Medical Research Laboratory where he worked in psychometrics and statistics and in computer applications for large-scale personnel selection and training systems, and at the Navy Safety Center, where he developed methods for determining special accident risk populations and identified human factors problems related to aircraft accidents.

CDR Lane holds a Ph.D in Quantitative and Engineering Psychology from Ohio State University. He is the author of more than 40 papers and presentations. While at the Naval Air Development Center, he has been responsible for major efforts in the computerization of the human factors engineering process, and has co-developed an extensive series of computer models for human engineering design. Other areas of current work include workload measurement, crewstation geometry, voice technology, and cost effectiveness methodologies, with emphasis on technology transition into system design.

Walter Leyland graduated from the College of William and Mary in 1958 with a B.S. degree in Physics. He received an M.S. in physics in 1961 from Virginia Polytechnic Institute, and an M.S. in Management Science from Lehigh in 1971. Mr. Leyland has been at the Naval Air Development Center since 1970 as an Operations Research Analyst, specializing in antisubmarine warfare systems. He has participated in and directed a variety of studies on development of analytical models for analysis and evaluation of ASW weapon systems. He is currently involved as supprot analyst for the Beartrap tracking algorithm and as a project manager in Weapon System Economic Analysis. Mr. Leyland has published 15 technical reports and publications.

Biographical Sketch

Melvin I. Strieb

Melvin I. Strieb is currently a Program Manager for Human Factors at Analytics in Willow Grove, Pennsylvania. He received a B.A. in Physics from Haverford College in 1966, and is currently pursuing an M.S. in Design and Management of Systems at Drexel University and is a candidate for a Ph.D in Anthropology at the University of Pennsylvania. Mr. Strieb has supervised and contributed to numerous efforts in digital simulation, information storage and retrieval, and hardware and software system design. He has been principal investigator for development of the Human Operator Simulator since 1973, and has made significant contributions in voice recognition and synthesis and in the development of automated crewstation design systems. He has developed software for 16 different computer systems, and has programming capability in five computer languages. He has authored or co-authored more than 25 technical publications.

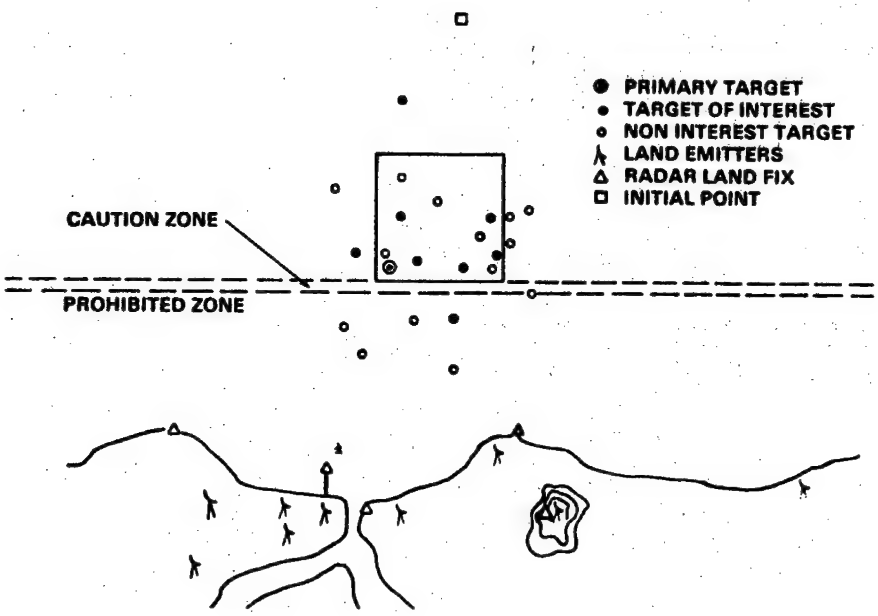

Figure 1. Layout of Anchorage area.

- RADAR
  - PLOT ALL TARGETS
  - PROVIDE NAVIGATION UPDATES EVERY FIVE MINUTES
- ESM
  - EVALUATE AND PROCESS PRECONTACTS
  - CORRELATE BEARING LINES WITH RADAR CONTACTS
- MISSION PLANNING
  - SELECT NEXT TARGET
  - FLIGHT PATH CONTROL
- RUN-IN
  - PERFORM ELINT PROCEDURES
  - TARGET TYPE DETERMINATION
  - MARK-ON-TOP PROCEDURES
- FLIR (WHEN APPROPRIATE)
  - PERFORM FLIR TRACKING (WHEN APPROPRIATE)
  - IMAGE ADJUSTMENTS
  - IMAGE RECORDING

Figure 2. Operator task groupings.

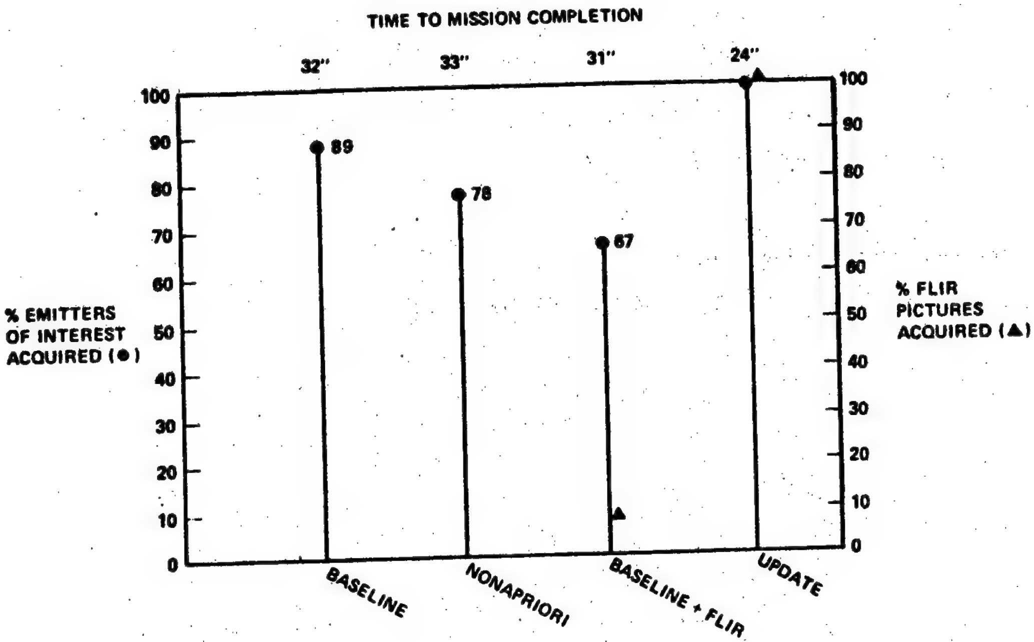

Figure 3. Summary of system performance.

- O & S COSTS PER FLIGHT HOUR (FH) = CR + RS + OOC + POL + SDLM + ER + P + IOC

WHERE:

CR = COMPONENT REWORK
RS = REPLENISHMENT SPARES
OOC = OTHER OPERATING CONSUMABLES
POL = PETROLEUM, OIL, LUBRICANTS
SDLM = STANDARD DEPOT LEVEL MAINTENANCE
ER = ENGINE REWORK
P = MILITARY PERSONNEL
IOC = INDIRECT OPERATING COSTS

- BASELINE (P-3C)
  O & S COSTS/FH = 2,682 + 1,029 = $3,711/FH

Figure 4. Operations and support (O & S) cost elements.

CONFIGURATION	OSFT (MIN)	O&S COSTS ($/FH)	OSC ($)	EI (%)	FP (%)
BASELINE	31.70	3,711	1,961	89	–
NONAPRIORI	32.68	3,711	2,021	78	–
BASELINE & FLIR	31.38	3,723	1,947	67	8
UPDATE	24.07	3,763	1,510	100	100

WHERE: OSFT – ON-STATION FLIGHT TIME
OSC – ON-STATION COSTS
EI – % OF EMITTERS OF INTEREST
FP – % OF FLIR PICTURES

Figure 5. On-station cost and data summary.

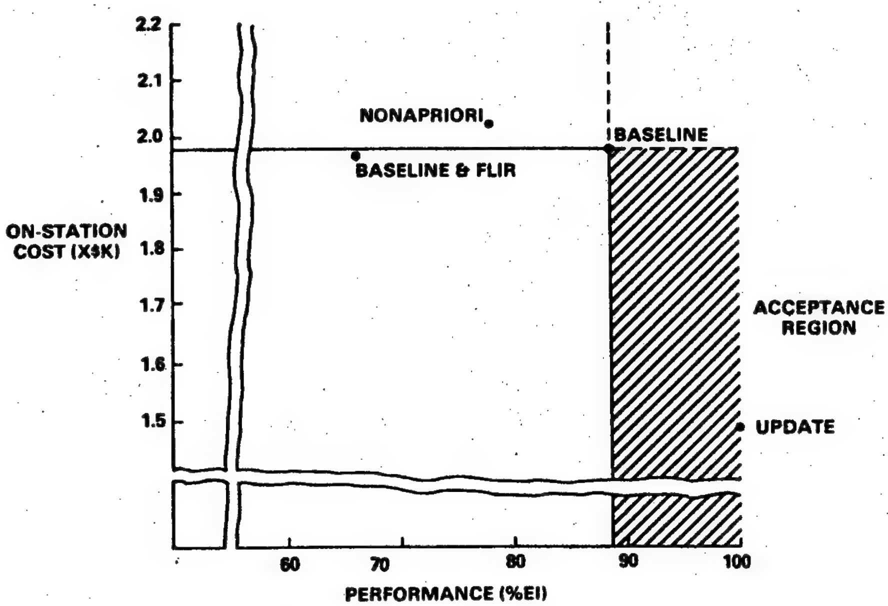

Figure 6. Relative costs effectiveness analysis of Anchorage (ESM).

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AN INFLIGHT PHYSIOLOGICAL DATA ACQUISITION AND ANALYSIS SYSTEM

BY

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An Inflight Physiological Data Acquisition and Analysis System

Abstract

The United States Air Force School of Aerospace Medicine and the United States Navy Pacific Missile Test Center have developed a system capable of monitoring, recording and analyzing selected physiological responses of aircrewmembers engaged in flying activities. The airborne instrumentation is battery-operated and completely man-mounted. Furthermore, it is modular in design to allow its volume and weight to be distributed over the aircrewmember's torso in order to minimize its interference with his personal equipment and his freedom of movement. The device can record up to 20 channels of analog data; or, when combined with an optional cardio-thermal module, it can record a mix of 12 channels analog and 32 channels digital data. The data are multiplexed on a four track magnetic tape cassette. The specific data currently recorded include inspired and expired respiratory gas flow rates, inspired and expired oxygen partial pressures, ECG/heart rate, skin temperatures, acceleration, cabin pressure, cockpit voice communications, and a timing signal. The ground-based components of the system include a data playback device, a portable field data processor for simple, straightforward analysis in the field, and a laboratory data processor for more rigorous data analysis and plotting.

INTRODUCTION

The United States Air Force School of Aerospace Medicine (USAFSAM) and the United States Navy Pacific Missile Test Center (PMTC) have been engaged in a program of inflight data acquisition and analysis for the last several years (Ref. 1-3). This program grew out of a need to measure, under actual flight conditions, the physiological responses of pilots and other aircrewmembers to the ever-increasing physical demands being made on them by modern weapons systems and flying missions. The objectives of this program have been to evaluate the effectiveness of life support equipment and systems, determine the oxygen generation and storage requirements for various types of missions, accumulate a data base from which design criteria for new breathing systems and environmental control systems can be developed, and assess the physiological cost of flying operations.

The instrumentation development described herein began as an attempt merely to upgrade the existing USAFSAM physiological monitoring device (Ref. 4), but it quickly developed into an entirely new concept. The system is presently in its engineering development stage, with several refinements yet to be made before the final designs are frozen. When fully operational, it is expected to be of significant value in supporting the biotechnology research of USAFSAM and PMTC as well as in providing biomedical support to test centers and operational flying commands, the latter being a rapidly emerging thrust in the USAFSAM program.

DESCRIPTION

General

A functional flow diagram of the total system is shown in Figure 1. The components of the system are:

1. Airborne Instrumentation
2. Data Reproducer (playback device)
3. Field Data Processor
4. Laboratory Data Processor (DECLAB 11/03).

A description of each of those subsystems is given in the following paragraphs.

Airborne Instrumentation

Due to the requirements that it be non-invasive to the aircrewmember and aircraft and, when used in fighter-type aircraft, not interfere with

the emergency ejection sequence, the airborne instrumentation was designed to be completely man-mounted and battery-operated. The instrumentation is in modular form so that the various assemblies can be arranged in the optimal pattern on the aircrewmember's torso in order to minimize its interference with his personal equipment and his freedom of movement. That feature also allows the combination of modules having the minimum volume and weight, commensurate with the data requirements of each particular study, to be fit to the subject. The airborne instrumentation is comprised of the data acquisition module, mask assembly, flow transducer module, and cardio-thermal module.

The data acquisition module is capable of monitoring, conditioning and recording data for four continuous hours. The sensors and signal conditioning consist of an electrocardiogram (ECG) amplifier/rate monitor, an absolute pressure transducer, an accelerometer, oxygen sensor circuitry, and an audio amplifier. The conditioned signals are time multiplexed by three 8-channel analog multiplexers and recorded on a standard four track magnetic tape cassette using a pulse duration modulation (PDM) format, as shown in Figure 2. Each multiplexer is dedicated to a particular track of the magnetic tape. The fourth track is used entirely for audio recording. An internal clock generates a 16-bit timing signal which is initialized when power is applied. Four channels on Track I are used to record timing information, leaving a total of 20 analog channels for data. The system will accept any input in the range of 0-5 volts. Each channel is sampled 32 times each second; however, all multiplexer inputs are connected to an external plug to facilitate cross-strapping of higher frequency data. The six volt battery and its associated ±12 volt DC-DC converter, also installed in this module, power all of the module's circuitry in addition to that of the oxygen sensors, the flow transducer module, and the cardio-thermal module. The size of the engineering development version of this module is approximately 6.9 x 4.3 x 2.2 inches (17.5 x 10.8 x 5.6 cm) and weighs 3.3 pounds (1498 gm). Further refinements are planned which may reduce the size and weight of this module.

The mask assembly is a modified standard Air Force issue MBU-5/P oxygen mask. The modifications are made to facilitate the interface of two sub-assemblies that are used to measure respiratory gas flow rates and the associated partial pressures of oxygen. One sub-assembly is installed on the inspired side of the mask, and the other is installed on the expired side.

The inspired sub-assembly consists of an aluminum "T" fitting, attached in-line to the oxygen inlet hose, into which the inspired oxygen partial pressure sensor is installed. A fixed, sharp-edged orifice is built inside the fitting, in the path of the inspired flow. The orifice is of sufficiently small diameter to produce a measurable pressure drop in the line during inspiration, without causing excessive resistance to breathing. The pressure drop across the orifice is measured by means of pressure taps on the upstream and downstream sides of the orifice which

connect via semi-rigid small bore tubes to a differential pressure transducer (in the flow transducer module). The differential pressure thus measured is converted to a gas flow rate (liters/min) measurement during calibration.

The expired sub-assembly consists of a plastic fitting which clamps into the expiration port of the oxygen mask. The expired gas is routed through that fitting and is then vented to the atmosphere through a set of three sharp-edged orifices, producing a pressure differential between the inside of the fitting and ambient conditions. The pressure upstream of the orifices is transmitted via a single semi-rigid small bore tube to the expired differential pressure transducer (in the flow transducer module). Only one tube is required because that differential pressure transducer is referenced to ambient conditions. Additionally, the pressure created inside the expired sub-assembly during expiration is used to drive a 200 cc/min (standard conditions) sample of expired gas through a drying bed of molecular sieve and then to the expired oxygen partial pressure sensor, which is installed in the fitting. The drying bed is necessary because water vapor introduces error in the oxygen partial pressure measurement.

All interphone and air-to-ground communications are monitored and recorded by means of a single wire tap into the headset side of the mask interphone cord. The tap is made by introducing an adaptor/connector between the mask interphone cord and the aircraft interphone cord.

The flow transducer module contains two differential pressure transducers and their signal conditioning circuitry. The transducers are connected to the inspired and expired respiratory gas collection sites by means of the semi-rigid small bore tubes discussed in the previous paragraphs. Power to operate the transducers and their associated circuitry is provided from the data acquisition module. The size of the flow transducer module is approximately 1.5 x 2.0 x 3.3 inches (3.8 x 5.1 x 8.4 cm) and it weighs approximately 1.0 pound (454 gm).

The cardio-thermal module will condition, sample, digitize, and output eight body temperatures and ECG/heart rate. The assembly consists of eight linear thermistor probes, associated signal conditioning, an ECG/rate monitor and a pulse code modulation (PCM) encoder. Power is provided from the data acquisition module. A 32-channel analog commutator is used to sequentially sample the signal inputs from the thermistor probes and ECG electrodes. The outputs of the commutator are digitized by a PCM encoder. The PCM output is a biphase 1 KHz signal which directly drives Track III on the recorder head of the data acquisition module. The size of this module is approximately 2.25 x 4.0 x 1.0 inches (5.7 x 10.2 x 2.5 cm) and weighs 0.44 pounds (200 gm).

In the man-mounted configuration, the data acquisition module and flow transducer module are installed in a modified SRU-21/P survival vest.

The modified MBU-5/P oxygen mask is attached to the standard Air Force helmet (HGU-26/P), and the cardio-thermal module is worn under the flight suit and held in place with a special belt. Although the airborne instrumentation will be employed in the man-mounted configuration for most applications, it has been sized for easy installation on the pilot's side console of most U.S. military aircraft.

Data Reproducer

The data reproducer, or playback device, is used to convert the PDM signals recorded by the data acquisition module to analog signals. The reproducer consists of a tape drive, a timing decoder, a binary-to-BCD (binary coded decimal) converter, three signal integrators, and associated signal de-multiplexers. The timing information is extracted from the tape, converted to BCD and output to a BCD display. The outputs of the analog de-multiplexers are connected to a cross-strapping switch to interconnect output channels for higher frequency data. The voice channel is fed into an audio amplifier and speaker. A 24-position rotary switch is used to sample any of the analog outputs and display the analog voltage on a liquid crystal display (LCD) digital voltmeter. When the cardio-thermal module has been used to record PCM data on Track III of the cassette tape, those data are reproduced by means of a microprocessor-based PCM decommutator. In that case, cross-strapping between channels is done via software. A keyboard for entering that information is provided. The reproducer is capable of operating in a pre-programmed time mode in which the start and stop times of the required portion of data may be entered via the keyboard and an automatic time search of the tape is initiated and controlled by the processor. Outputs consist of 30 analog channels and one 8-bit digital channel. The reproducer is permanently mounted in an aluminum carrying case with a hinged lid, and is easily transportable to and set up at field locations.

Field Data Processor

The portable field data processor, designated μE-80, was specifically designed by PMTC to operate in a test environment. The Z-80A microprocessor was configured to accept nearly any commercial peripheral device; i.e., ZILOG, INTEL, ADVANCED MICRO DEVICES, etc. Additionally, a Test Oriented BASIC language was designed to simplify data acquisition and analysis. The field data processor is primarily used for simple, straightforward analysis of data while deployed in the field. The μE-80 has integral analog multiplexers (32 channels), a 10-bit analog-to-digital converter, and digital I/O ports. The device uses 11K bytes of eraseable-programmable read-only memory (EPROM) and 24K bytes of random-access memory (RAM).

The data reproducer/field data processor configuration is shown in Figure 3. Analog data from the data reproducer is transformed to digital data by an A-to-D converter integral to the field data processor. Digital

data from the reproducer (recorded from the cardio-thermal module) is entered directly via the digital input ports of the field data processor. Control signals from the field data processor are used to control the reproducer; i.e., rewind, fast forward, play.

A typical data reduction/analysis sequence is shown in skeletal form in Figure 4. The field data processor sends out a control signal to insure the tape is rewound and then starts reading data. Data is analyzed in a rate-adaptive manner; i.e., once initialized, data is ignored until changes occur beyond some pre-set threshold (sensitivity). Once the internal buffers are filled, the reproducer is stopped and the analyzed data is transferred to a digital cassette tape and, at the operator's option, displayed on a printer and/or other terminal device. The process then continues until all the data has been analyzed.

The Test Oriented BASIC interpreter developed for the μE-80 is similar to Dartmouth BASIC but contains special features to interface to equipment normally used in a test environment. Also, all arithmetic operations are performed with an arithmetic processing unit (AMD 9511) and the execution speed is therefore very fast. In a comparison (benchmark) with four other interpreters (including the DEC BASIC for the PDP 11/03), the Test Oriented BASIC performed a group of arithmetic operations at least 40% faster than any other BASIC.

Laboratory Data Processor

More rigorous data analysis is performed with the laboratory data processor, a Digital Equipment Corporation DECLAB 11/03 minicomputer. Data analysis with that device is similar to that of the field data processor except that a floppy disk is used for mass data storage rather than a digital cassette. Additionally, the DECLAB 11/03 can display analyzed data on a graphics plotter. It should be noted that DECLAB analysis is performed in FORTRAN and by linkages to PDP-11 assembly language routines. Plans are being made to interface this machine to the USAFSAM computer network currently being developed. Once that task is accomplished, it will be possible to store the accumulated inflight data in a data base management system for selective retrieval and manipulation.

DISCUSSION

USAFSAM is being tasked more and more heavily to provide biomedical guidance based on inflight collection of physiological data. The present data collection capabilities are presented in Table I. Planning is underway to expand the capabilities to include many other types of physiological and environmental data, such as electromyogram (EMG), electroencephalogram (EEG), tri-axial acceleration, blood pressure, expired carbon

dioxide concentration, and blood oxygen saturation. Adequate sensors already exist for some of these measurements, but, for the others, suitable non-invasive sensors have yet to be developed.

The Inflight Physiological Data Acquisition and Analysis System described in this paper has been designed so that new sensors and transducers can be integrated into the system with minimal effort. In addition to having that high degree of versatility, it is a complete system which takes data from the collection site all the way through simple analysis and tabulation in the field to more rigorous analysis in the laboratory. The system will tremendously enhance the ability to process large amounts of data very efficiently and provide rapid responses to test and evaluation requests from customers in the field.

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Table I
Present Capabilities for Inflight Data Collection

Parameter	Instrumentation Device	Measurement Range
Inspired Flow Rate	Differential Pressure Transducer (Senso-Metrics, Model SP-65, ±0.3psid)	0 - 240 liters/min
Expired Flow Rate	Differential Pressure Transducer (Senso-Metrics, Model SP-65, ±0.3psid)	0 - 160 liters/min
Inspired Oxygen Partial Pressure	Polarographic Sensor (Beckman Model OM-11)	0 - 760 mmHg
Expired Oxygen Partial Pressure	Polarographic Sensor (Beckman Model OM-11)	0 - 760 mmHg
G_z	Accelerometer (Humphrey Model LA45-0101-1)	-10 to +10 G_z
Cabin Pressure	Absolute Pressure Transducer (Bourns Model 80294-2005852008)	0 - 15 psia
ECG (waveform)	ECG Preamplifier (PMTC Hybrid Circuit)	2 volts peak-to-peak
Heart Rate	ECG Preamplifier; cardio-thermal module (PMTC Hybrid Circuit)	50 - 200 beats/min
$Temp_1$ to $Temp_8$ (skin/body)	Thermistors; cardio-thermal module (YSI 709 Series Probes)	20 - 50° C
Time	BCD Clock (PMTC Hybrid Circuit)	0 - 65536 Sec
Audio	Electrical Tap to Intercom Cord	All cockpit communications

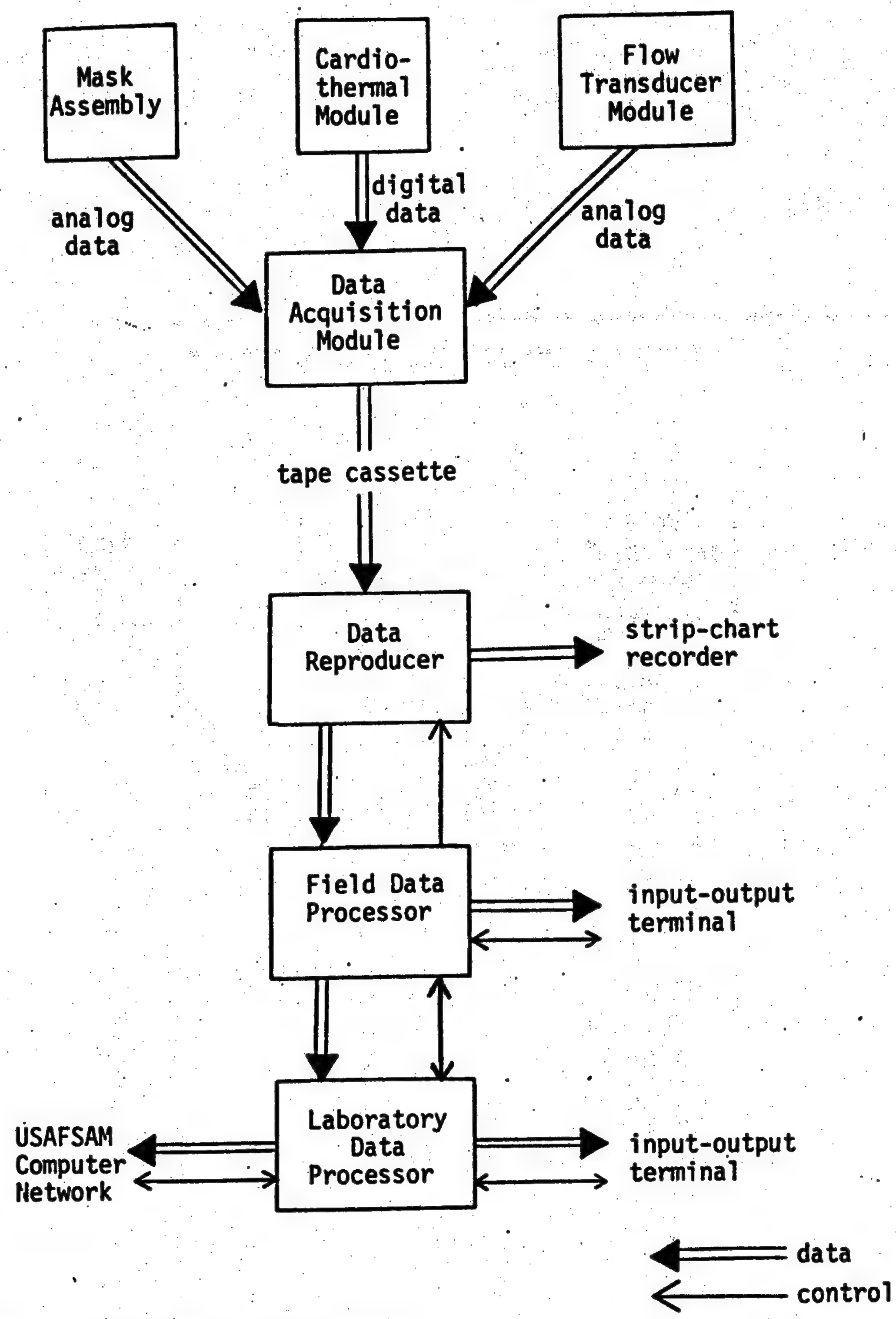

Figure 1. Functional Flow Diagram.

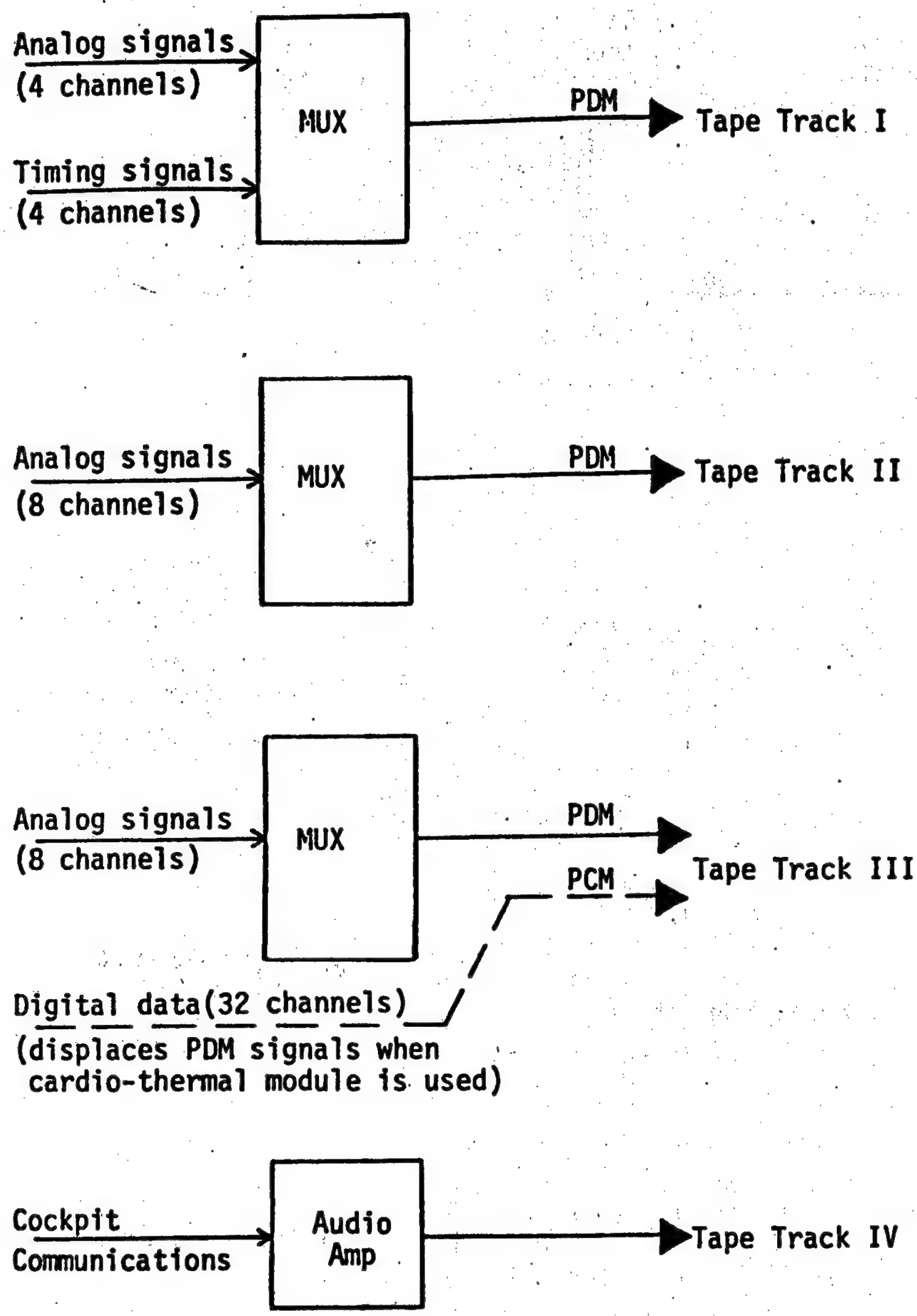

Figure 2. Electronic Configuration of Data Acquisition Module.

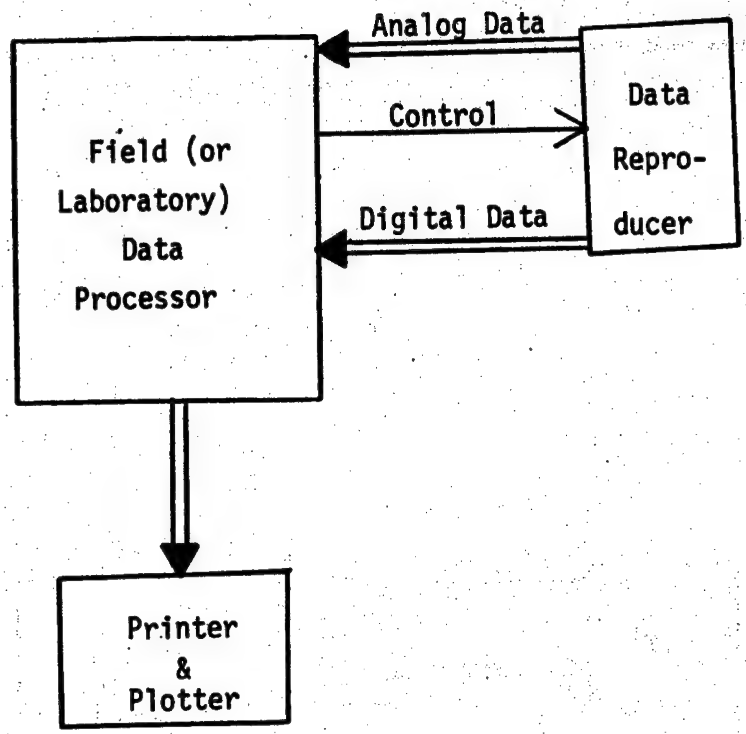

Figure 3. Reproducer/Field Data Processor Configuration.

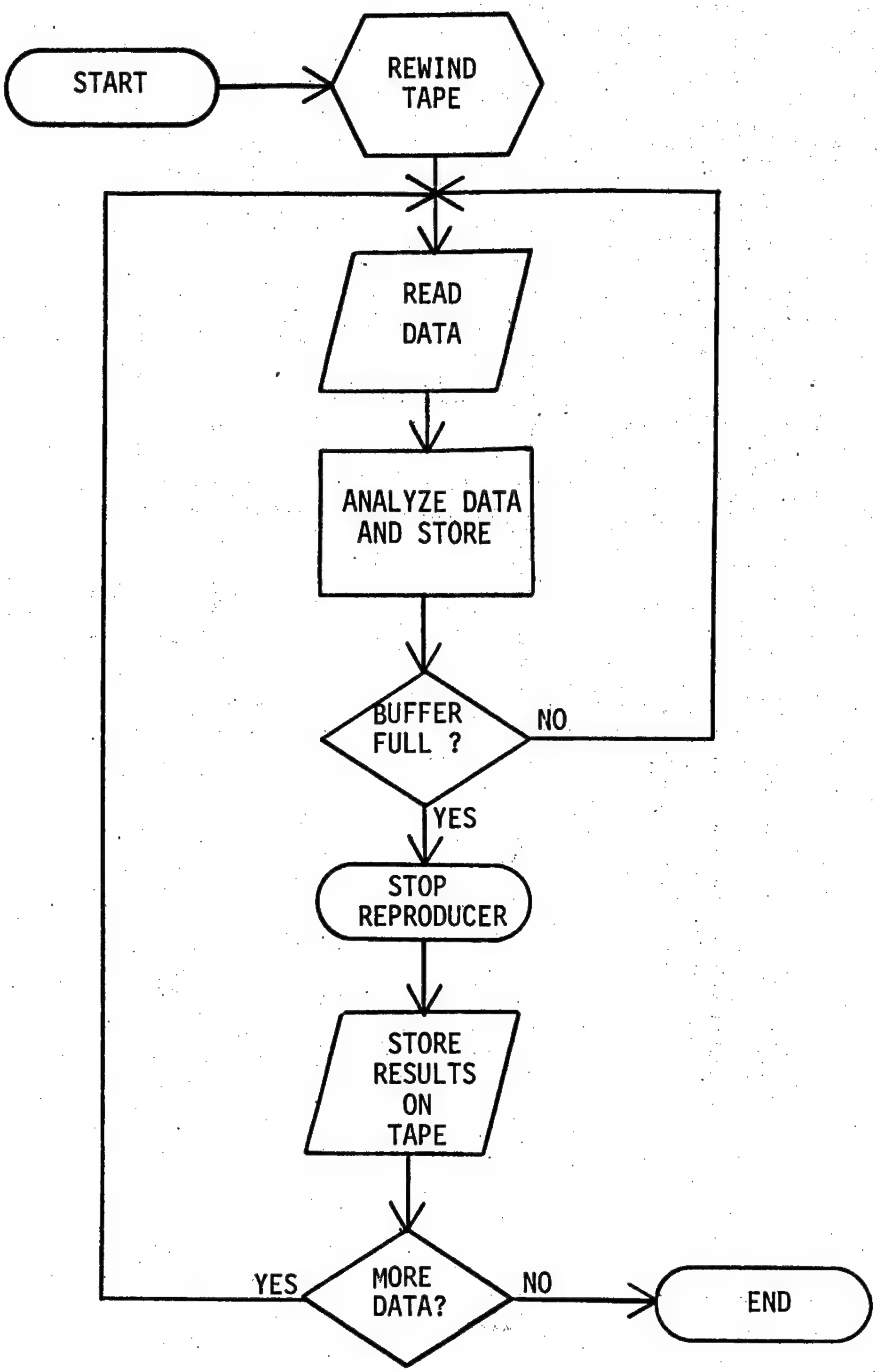

Figure 4. Typical Data Analysis Sequence.

ACKNOWLEDGEMENTS

The authors wish to express their sincere appreciation to Technical Sergeant Melvin A. Tays, who has participated in this system development since its beginning, contributing his expert advice and assistance in many areas. We also wish to thank Mr. Jim Scheid for producing the mechanical design, Mr. Gary Wingerter and Mr. Jim Russell for their contributions to the electronics design, other members of the Weapons Instrumentation Division of PMTC and the Crew Technology Division of USAFSAM, and Mrs. Mary Coen for her patience and skill in the typing and preparation of this paper.

Biographical Sketch

Captain John T. Merrifield was born in San Antonio, Texas on 14 February 1947. He received a B.S. degree in Engineering Science from Trinity University in 1968. He was commissioned in the Air Force in 1970. After completing Undergraduate Pilot Training in 1971, he flew C-141 aircraft at Charleston AFB SC until 1975. In 1976 he received an M.S. degree in Astronautical Engineering from the Air Force Institute of Technology.

In January 1977, Capt Merrifield began his current assignment as an engineer at the USAF School of Aerospace Medicine at Brooks AFB Texas. He is presently managing the inflight data acquisition effort at USAFSAM, the primary objective of which is to provide biomedical guidance to test centers and operational flying commands. He is also managing several contract and in-house efforts to develop state-of-the-art non-invasive instrumentation for application to inflight data collection studies. In addition, Capt Merrifield is a CT-39 Aircraft Commander, flying for the Military Airlift Command.

Mr. Theodore P. Waddell was born in Shield, North Dakota on 9 October 1933. He received a B.S. degree in Electrical Engineering from the University of Idaho in 1956. He has been employed from graduation to the present time for the U.S. Navy at Point Mugu, California. He has been involved in the design and implementation of special purpose instrumentation systems for the testing of a wide variety of Navy weapons and associated hardware. He has designed instrumentation components including transducers, signal conditioners, multiplexers, transmitters, antennas, receivers, demultiplexers, recorders and display devices. Additionally, he has served as a consultant to other organizations and agencies on instrumentation problems. Mr. Waddell shares a patent on a noise resistant data link for a doppler scoring system.

Mr. David G. Powell was born in San Bernardino, California on 26 January 1948. He graduated from California State University, Long Beach with a degree in Electrical Engineering in 1971. After graduation he accepted a position as an instrumentation design engineer at the Naval Missile Test Center at Point Mugu, California.

Since 1974 he has been head of the Process Engineering Section of the PMTC Microelectronics Facility working in the areas of thin films, thick films and linear integrated circuit development. He is the current project engineer for the Inflight Physiological Data Acquisition System and Miniature Environmental Monitor Development. He has published one paper on thin film advanced resistor technology and is a member of the International Society for Hybrid Microelectronics.

Mr. Eddie B. Croson is head of the Microelectronics Laboratory at the Pacific Missile Test Center, Point Mugu, California. Mr. Croson originated the microelectronics capabilities at Point Mugu in 1967 and fostered its growth such that its present capabilities include thick film, thin film and multi-chip hybrid microcircuits as well as processing capabilities for monolithic bipolar linear integrated circuits. The facility is regarded as a leader in hybrid microcircuit technology in the Navy.

Mr. Croson did his undergraduate work at the California State University at Fresno and received a BSEE. He is currently completing his graduate studies in Computer Science at the University of California, Santa Barbara. He has authored many articles and papers on electronic circuitry and microelectronics processing and holds two patents in hybrid microcircuit processing. Mr. Croson founded the Naval Microelectronics Working Group in 1974 and was appointed as the Chairman by the Director of Navy Laboratories.

Mr. Croson is a member of ISHM (International Society for Hybrid Microelectronics), IEEE and the IEEE Computer Society. He resides in Ojai, California with his wife and three children.

SYNTHETIC SELECTION OF NAVAL AVIATORS: A NOVEL APPROACH

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Synthetic Selection of Naval Aviators: A Novel Approach

Abstract

Increased interest in reducing attrition in Undergraduate Pilot Training has led to the proposed addition of a Synthetic Selection System to the traditional written aptitude test battery. The system includes tests for complex coordination, selective attention ability, reaction to motion stress, and selected cognitive and psychomotor skills. A major portion of the testing is devoted to the last two skills, using a device embodying recently developed adaptive training and testing concepts. Underlying use of the device is the notion that learning will take place in a well designed testing environment with immediate feedback. Hence, testing will be structured to apply the latest techniques for assessing and training potentially useful skills. The device does so by adapting a sequence of problems to the ability of individual students. Extensive record keeping is performed to enable automatic adjustment of adaptation rules to improve system performance. Data classifying students according to performance on other tests and in subsequent training will allow the system to cope with the changing nature of student input characteristics and downstream training requirements.

Introduction

Recent history has seen an acceleration in the cost of Undergraduate Pilot Training (UPT) within the Navy. This high per student cost, which presently ranges into the hundreds of thousands of dollars, has been brought about by the increased cost of fuel, manpower, and equipment. While fuel costs are relatively fixed in an upward direction, other costs of Navy UPT could be reduced through the increased precision of the tools used to select the trainees. Specifically, a reduction in the drop-out or attrition rate could lead to a reduction in the overall cost of UPT by the concentration of time, effort, and equipment on trainees who are more likely to complete the program. In a less economic, but equally important, vein a more efficient selection program can avoid the wasted time and frustration that can occur when low skill/aptitude people are placed in a program where their chances of success are minimal.

At the present time, the aviator selection program consists of various written tests designed to assess abilities related to piloting skills. These tests are the Academic Qualification Test (AQT), the Mechanical Comprehension Test (MCT), the Spatial Apperception Test (SAT), and the Biographical Inventory (BI). These tests have been shown to be valid predictors of success in UPT. These measures, although conceptually sound, do not account for a large amount of the variance in the criterion of attrition from UPT (North and Griffin, 1977). The present battery does a good job of predicting academic qualification (only about 2% of failures are academic) but does less well in predicting motivational or flight failures (60.5% and 21.5% of attrition, respectively, are due to these factors). This is not surprising given the nature of the criterion and the academic basing of the predictors. Authorities in the area of prediction of performance in occupational settings have suggested the use of more behaviorally based prediction measures (Wernimont and Campbell, 1968). These measures, or samples of behavior, are more often likely to have a stronger relationship to the criterion since they contain more kinds of behaviors that are also contained in the criterion. Various efforts have been made to improve the predictive efficiency of selection batteries used for UPT selection using behavioral measures. Most notable among these efforts is the Air Force's Automated Pilot Aptitude Measurement System (APAMS) (Long and Varney, 1975). This system used a general aviation simulator (the GAT-I) to give brief flight instruction and automated testing to prospective aviation trainees on basic flight maneuvers. This

method proved to be a useful way of predicting success in UPT for Air Force student pilots. In keeping with the trend toward more performance based measurement, the Naval Aerospace Medical Research Laboratory (NAMRL) has stated:

> The lack of any prominent breakthrough in perceptual/cognitive paper-and-pencil performance tests since World War II years suggests that non-paper-and-pencil performance tests should be investigated to determine their relationship to aviator performance. (North and Griffin, 1977, pg 35).

In order to follow through with this mandate, and to improve the predictive efficiency of the selection system thereby reducing attrition in UPT, NAMRL has moved to add several more instruments to the selection battery. The following describes these new test devices:

a. The Psychomotor Test Device (PTD) consists of a two axis tracking task that requires the examinees to track cursors with the simultaneous coordination of a footpedal and a joy stick. This is a test of complex psychomotor coordination.

b. The Dichotic Listening Test (D/L) requires examinees to respond, as directed, to either the right or left ear when two messages are presented to both ears simultaneously. This tests the examinees ability to selectively attend to different auditory channels.

c. The Brief Vestibular Disorientation Test (BVDT) determines the examinees' response to motion stress. They are placed in a rotating chair and required to respond to a digit repetition task while tilting their heads in various ways.

d. The Integrated Multitask Psychomotor and Cognitive Testing (IMPACT) System is a psychomotor test device designed to tap individual information handling and perceptual-motor capabilities. In the IMPACT system, examinees use a joy stick to keep a tracking cursor centered at a predesignated position on a screen while carrying out the cognitive processing activity of canceling digits with a key pad. During the course of this test information is also provided about the degree of successful performance on both tasks with regard to an adaptively set goal.

In addition to the above performance based tests, a more generalized adaptive training and testing device will be evaluated for inclusion in the selection testing for Naval UPT. This device, based loosely upon the APAMS mentioned previously and suggested in Diehl (1976), involves the short term training and automated testing of candidates for UPT on a low cost aviation simulator modeled after a device termed the trainalator presently under development at the Human Factors Laboratory of the Naval Training Equipment Center. Each unit of the system is comprised of a Digital Equipment Corporation PDP-11/34 minicomputer with 28k of MOS memory, a VT-11 video display unit, an RX11 dual floppy disk unit, a Votrax audio response unit, and a stick/throttle quadrant for student inputs. One unit has, in addition, an RK-06 cartridge disk for data base maintenance.

The system will be programmed to simulate the flight dynamics of the T-34C primary training aircraft. The graphics tube will display both the instruments of the T-34C aircraft and the scene that appears out of the window. Trainees will use the instruments and the visual reference to accomplish the maneuvers during the training/testing sessions. The IMPACT portion of the selection battery will be included on the trainalator device and will serve as an introduction to the T-34C simulation by training examinees in the relationship between stick movements and attitude indicator responses. During the IMPACT portion of the training/testing sessions, the examinees will be given the same test as described above under IMPACT with the exception that the tracking task will be done using the attitude indicator rather than the tracking ball. This provides for testing on the IMPACT system with a high degree of realism or face validity and leads into the early training in instrument-control input relationships given on the synthetic selection system.

The initial phase of synthetic selection system operation will involve the instruction of the candidate in the basics of flying and will advance them through the trainalator system to sophisticated simulated flight maneuvers such as flying a rectangular course with cross wind. As the examinees progress through the syllabus, the adaptive logic of the program will speed up the training process by taking individual trainee skills into account. In addition, the computer system will keep track of, and store for future analysis, trainee performance on the system. The system will be comprised of modularized testing units which will allow for the expansion and addition of tasks as future needs dictate. For example, brief training in the meaning of and

responses to the annunciator panel could be given and included in the training and testing sessions.

The flexibility will also provide for the modification of the system as it responds to feedback from the training units. This will be accomplished by the flow of data back from the various stages of Undergraduate Pilot Training. This data will be placed into the computer system and will grow to form a data base of performance histories. This performance history data will be used for subsequent modification of the selection system's cut-off scores and for addition or deletion of test modules. As time goes by, and a large amount of student performance data is placed into the system, a greater degree of precision in predicting UPT success should be attained. As the system is refined, by the flow of such data, the prospect for using the synthetic selection system in order to determine to which specific area of flight training a candidate should be assigned becomes a further possibility. Through continued use the system may be able, based upon trainee scoring, to allow for the determination of, not only whether or not a specific student can be trained to fly, but what type of pilot training the student has the highest probability of completing successfully. Used in this way, the system becomes a valuable tool for setting the maximum benefit from training by making fine distinctions between students as to their suitability for specific types of training. In addition, as new aircraft enter the inventory and training objectives change, or the nature of the student input to the training system changes, the synthetic selection system will be automatically adapted or shifted in the nature of the tasks taught and the tests given.

Once installed, the synthetic selection system will be subjected to an 18-month long evaluation of the validity of the approach. Five 2-hour blocks per examinee are being set aside to run the initial group through the synthetic selection system during one week testing periods prior to UPT. This study will be conducted with approximately 400 Aviation Officer Cadets in the Navy's primary flight school at Pensacola, Florida. These students will be tracked throughout UPT to determine the degree of effectiveness the synthetic selection system training and testing has on prediction of attrition from UPT. It is expected that the proposed system, that features the T-34C simulation for training and testing will reduce attrition substantially, with a possible savings of $600,000 for every percentage point of attrition reduced.

One area in which the synthetic selection system should show the greatest promise is in the reduction of motivational attrition. The selection process can be conceived of as a two-way decision process. The organization makes the hiring decision based upon skill and adaptability information gathered from the prospective candidate. The candidate makes the decision to join based upon relevant information about the organization and the tasks he or she will be required to perform. The synthetic selection system provides a unique opportunity for prospective Naval aviators to gather accurate information about military aviation and make a decision about performing such an activity on a daily basis. If this decision can be made prior to participation in the actual training program, a substantial waste of time and resources can be averted.

In that the system represents an integrated testing of specific skills directly related to the activity of controlling an aircraft in flight, flying deficiency attrition should also be reduced. The short training sessions should give the Navy data about the degree of training required by certain trainees. Given the adaptive nature of the system, it can be determined just how much longer than average certain trainees may require to learn the flying skills involved. This allows for a weeding out, early on, of the trainees who might require an excessively long training period.

A further benefit of the system lies in the fact that it is insensitive to irrelevant characteristics of the examinees. The only aspect of the examinees that will be monitored by the system will be the degree of progress through the training and the collection of examination scores. As a result, the system should be less susceptible to charges of unfairness or discrimination based upon the sex or race of the examinee.

As data is gathered about the progress of trainees in UPT and fedback to the system, greater precision will be attained with regard to prediction to specific UPT pipelines. The future intention is to channel the trainees into different avenues based upon their performance in the synthetic selection system. Although this feedback aspect of synthetic selection is a novel approach at the present time, the near term prospects for monetary savings and the overall flexibility and simplicity of the system should make it commonplace in the assessment of potential for success as a pilot.

Biographical Sketch

Born September 20, 1940, Don Norman graduated with a B.S. in Electrical Engineering from Oklahoma State University in 1963. While attending Texas Christian University for graduate work in psychology, he became associated with Life Sciences, Inc., initially on a part time basis. Over the next decade he progressed from Research Assistant to Staff Scientist and Project Director. In 1973, he joined the Human Factors Laboratory of the Naval Training Equipment Center, continuing development of computer applications to aviation training. He has published more than 15 papers and technical reports in this and related areas. He is a member of the American Institute of Aeronautics and Astronautics and is President of the Central Florida Chapter of the Human Factors Society.

Dennis Charles Wightman was born in Orlando, Florida on October 10, 1948. He received a B.A. in psychology from Florida Technological University in 1972 and a M.A. in psychology from the University of South Florida in 1977. He is presently completing the requirements for the Ph.D. in industrial/organizational psychology from the University of South Florida.

In January 1978, he joined the staff of the Human Factors Laboratory at the Naval Training Equipment Center where he works as a psychologist. His area of interest is in the development of aviation training systems with special emphasis on the problem of pilot performance measurement and adaptive training. He is a member of the Human Factors Society and is a student in psychology member of the American Psychological Association.

Commander Lewis Edward Waldeisen was born in Cleveland, Ohio on December 16, 1937. He graduated with a B.S. in psychology from the University of San Francisco in 1960. He received a M.A. in psychology from the University of New Mexico in 1965 and a Ph.D. in human engineering psychology from Texas Technological University in 1973. In 1977 he became a registered professional engineer in safety engineering.

Commander Waldeisen served as assistant battalion operations/intelligence officer with the U.S. Marine Corps from 1960 to 1963. In 1966 he joined the Naval Aerospace Medical Institute (NAMI) as an aerospace experimental psychologist. While at NAMI he worked on the design of a large-scale computer performance measurement system. In 1970 he left NAMI to go to Texas Technological University where he designed an automated laboratory for the psychology department. From 1972 to 1974 he was human factors program manager for the LAMPS MKIII (helicopter) development program at the Naval Air Development Center (NADC). After leaving NADC in 1974, he was assigned to the Naval Postgraduate School in Monterey, California. In 1978 he came to the Naval Aerospace Medical Research Laboratory to his present position as Chief of the Human Factors Engineering Psychology Division. Commander Waldeisen has authored or coauthored 11 research publications and 10 professional conference presentations.

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MODELING
THE AIR FORCE MANPOWER AND PERSONNEL SYSTEM
FOR POLICY ANALYSIS

BY

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Modeling the Air Force Manpower and Personnel System for Policy Analysis

Abstract

The problem of accurately predicting the overall response characteristics of the Air Force Manpower and Personnel System (AFMPS) to high-level policy changes is important and difficult. The problem is important because decision makers require accurate information that is plausibly derived to make good and justifiable decisions. The problem is difficult because the AFMPS is a complex, functionally specialized system with response characteristics that are often non-intuitive. Though each functional specialty employs numerous special purpose models germane to its own interest, no total system model exists. Yet, much of the important AFMPS behavior results from interactions, interfaces, and interdependencies among the functional specialties. As a result the overall response characteristics of the AFMPS to policy changes is extremely difficult to predict with any real degree of confidence. Simulating the AFMPS as a single, integrated, feedback control system would provide decision makers with information of a fundamentally different type and make possible high-confidence predictions of systems response to policy changes. This paper describes, in three parts, the efforts of the Air Force Human Resources Laboratory to develop an Integrated Simulation Evaluation Model (ISEM) of the AFMPS. First, a conceptual model was devised to apply the concept of simulation to the AFMPS; this is often the most difficult step in a simulation. Second, a small, scaled-down prototype was developed to demonstrate the feasibility of simulating the AFMPS. The feasibility of this approach was favorably evaluated by a panel of AFMPS managers and noted civilian scientists. Third, the prototype is presently employed in assessing: (1) model utility and validity, (2) model sensitivities to data disaggregation and model detail, and (3) cost/benefit of full-scale development.

Introduction

This paper describes the efforts of the Air Force Human Resources Laboratory to develop a policy analysis tool capable of predicting and analyzing how the Air Force manpower-training-personnel system responds to policy changes. Efforts have centered around a model called the Integrated Simulation Evaluation Model--or, as it is better known, ISEM. Essentially, ISEM is a general purpose, large-scale simulation of the Air Force Manpower and Personnel System (AFMPS) and is designed to facilitate policy analysis. This paper is a project overview which first discusses the problem of policy analysis in large, complex systems like the Air Force Manpower and Personnel System and the use of simulation for coping with these problems. Next, the model devised at the Laboratory to apply the concept of simulation to the problem of policy analysis is presented. This will be followed by a short discussion of the research problem which consists of the results of two previous efforts and a problem evaluation. Finally, ongoing research is discussed.

Problem and Approach

Every organization whether it is large or small has a set of rules and regulations designed to maximize organizational effectiveness. When organizations are small, these rules and regulations are often quite easy to devise. If two people attempt a specific task, it may be very evident what policies are needed to maximize organizational effectiveness. However, as organizations become large, complex, and functionally specialized like the Air Force, making policy that maximizes organizational effectiveness becomes much more difficult. For instance, policy made in one particular functional specialty may work extremely well for that functional specialty but that policy may have unanticipated consequences in other functional specialties in that organization. These unanticipated consequences tend to be non-intuitive and difficult to predict by most methods. Thus, the problem of deciding what policy should be or what the effects of a policy might be, becomes very difficult in these complex organizations. However, the concept of simulation seems to be well suited for coping with these problems. ISEM is a simulation of the Air Force Manpower and Personnel System--a model of a system that "plays" upon a computer and simulates how the system behaves as time passes. Simulation has obvious advantages

for policy analysis. To determine the potential consequences of changing a particular policy, the policy change is first made within the computer, the passing of time is simulated, and the results are analyzed to gain a better idea of how one might expect that system to react to a particular policy change.

The project has concentrated upon providing the high-level decision maker with a policy analysis tool which is fundamentally different from present policy analysis techniques. Naturally, there are already many models within the AFMPS. These models tend to be heterogeneous and non-integrated--and rightly so, since these models are designed for special purposes and generally seem to perform rather well. At best it is difficult to perform high-level policy analysis using a piecemeal conglomerate of special purpose models. ISEM employs a "total systems perspective" and is designed to analyze high-level policy issues such as: What is a more desirable force mix of active and reserve forces? How might the AFMPS be expected to behave if various proposed changes were implemented in the retirement system? How could force reductions be made more effectively?

ISEM does not purport to solve any of these problems, rather ISEM would provide the decision maker with improved information. This is important for two reasons. First, in the long run a decision maker's decisions can be expected to be no better than the information upon which they are based. Second, after a decision maker has made the finest possible decision, it is of little value if he cannot sufficiently justify his decision to have it implemented. To have a problem and the concept of simulation for coping with that problem is one thing, but before the concept can be applied a model of the Air Force Manpower and Personnel System is needed.

Model

The basis for this model of the Air Force Manpower and Personnel System was originated by Capt Jon Knight at AFHRL in 1974 and consists of three elements: (1) the Internal Structure of the Air Force Manpower and Personnel System, (2) the environment that the Internal Structure exists within--the National Skills Market, and (3) a User Interface System.

The Internal Structure of the Air Force Manpower and Personnel System consists of three sub-elements or modules. This includes a Policy Information Control System, a Training and Transportation Pipeline, and a Personnel Force Structure. The Policy Information Control System, or the PIC, models the network which implements the manpower and personnel policy within the Air Force. This is simply to say that it is a policy data base. It is the control system which controls the rest of the model. Now consider the Personnel Force Structure. The Personnel Force Structure represents the skilled manpower talents available to the Air Force with which to accomplish its mission. This module is essentially a personnel data base representing aggregations of specific manpower skills assigned to particular units at specified geographic locations. In the simplest terms, the model represents resources (the Personnel Force Structure) and the policies (the PIC) which regulate how the resources are applied to accomplish the mission. However, policy cannot directly change how a resource is employed. Policy can specify what skill in which a resource should be trained or where the resource should be located (assigned), but policy does not train or transport. Rather, trains, planes, and cars and instructors, books, and schools do that--this function is represented by the Training and Transportation Pipeline. The pipeline conceptually connects the PIC with the Personnel Force Structure. These three elements model the Internal Structure of the Air Force Manpower and Personnel System. Of course, this exists within an environment and that environment is the National Skills Market.

The National Skills Market models the influence that the national labor market exerts upon the Air Force's ability to recruit and retain personnel. When unemployment is high, it appears to be easier for the Air Force to recruit personnel than when unemployment is low, though our need to recruit may be lowest when unemployment is high due to reduced attrition and increased retention. Since the ability of the Air Force to recruit and retain personnel may constrain the quantity and quality of personnel available to the mission, it is important to consider these factors. The National Skills Market module attempts to model these influences.

The User Interface System interfaces the user with the simulation by providing information about what has occurred within the simulation. It will contain a variety

of measures. On the less exotic side, it will report routine management statistics such as PCS rates, year-end strengths, and technical school utilization rates. Second, the User Interface System will employ more sophisticated techniques such as goal programming to produce complex measures and human resources accounting. One example of this type of measure would be, What is the most demanding wartime scenario that a particular configuration of "faces and spaces" could meet? Thus, the User Interface System is simply a way of gaining information from the simulation.

This is the basic concept that was originated in 1974. Naturally it has grown, it has evolved, it has matured. Still recognizable pieces of this conceptual model can be identified in the prototype. This description greatly simplifies ISEM, but it captures the essence of ISEM.

Research Program

Based upon the strength of this concept, the Air Force Human Resources Laboratory let a contract to the CONSAD Research Corporation in 1975 to develop a methodology for applying the concept of simulation to the problems of policy analysis in the Air Force Manpower and Personnel System. The results of this research appeared to be quite promising. However, it is one thing to have a concept for coping with a problem and even a methodology for applying the concept to the problem, but it may be much more difficult to translate that methodology into something as concrete as lines of computer code.

Based upon the strength of the concept and the initial methodology work, the Air Force Office of Scientific Research (AFOSR) became interested in the research, and along with the Laboratory, desired to demonstrate the feasibility of implementing this methodology. Therefore, an ISEM prototype contract was let. It was funded by AFOSR and again it went to CONSAD Research Corporation under the close technical supervision of AFHRL. The contract was for a small, scaled-down version of ISEM, but the prototype is still a reasonable representation of the AFMPS. The Air Force in the prototype contains 91 skills (40 officer skills and 51 enlisted skills) including pilots, navigators, aircraft mechanics, supply specialists, veterinarians, etc. It contains weapon systems like the

B-52, the F-111, and the KC-135. It has 17 bases. These include a training base, a BMT base, and an OTS base. It has an APO on the east coast and an APO on the west coast, two European bases, two Pacific bases, and several CONUS bases. Most of the variables are there. Thus, the prototype is a small scaled-down model of the Air Force Manpower and Personnel System designed to demonstrate the feasibility of the ISEM concept.

At this point in the research, the Air Force Human Resources Laboratory and the Air Force Office of Scientific Research desired an independent objective evaluation of ISEM to determine the potential value of ISEM to the Air Force and the appropriateness of our technological approach. To accomplish this, an evaluation panel consisting of military managers and civilians with a rich mixture of relevant military and civilian expertise was convened on 17 and 18 March 1977 in Washington, D.C. As a result of the evaluation by this panel, it was concluded that ISEM is a very promising concept of potentially great value to the Air Force. However, the panel, like AFHRL, realized that before a wise and prudent decision could be made on the full-scale development of ISEM, several important questions must be answered. They also concluded that the ISEM prototype was quite powerful and should be employed in answering questions about model validity and cost/benefit. Based upon the strength and credentials of the persons involved in the evaluation panel, their recommendations have served as the basis for a research plan.

The objective of the research plan is to answer the cost/benefit questions associated with ISEM in order to provide a basis for a decision on the full-scale development of ISEM. This objective has been translated into three current research efforts. The first is a Prototype Test and Evaluation. The second is a Sensitivity Analysis, and the third is the Cost Benefit Analysis.

The purpose of the prototype test and evaluation is to determine the potential utility and validity of a full-scale ISEM. Essentially the evaluation panel recommended two things. First, that the prototype be installed on the AFHRL UNIVAC 1108, which has been done. Second, that researchers work very closely with potential users to test the capabilities of the prototype and to evaluate its utility and validity. In an iterative cycle, scenarios are developed in close coordination with potential users.

Next, the prototype is exercised, and researchers interact with potential users to determine the reasonableness of the results. At this point the first step is repeated. Scenarios are refined and the model adjusted if required, the prototype is exercised, and researchers again interact with potential users. This iterative cycle continues until the capabilities of the prototype for dealing with that particular scenario are assessed. Naturally, model validation requires an in-depth knowledge of how the AFMPS responds to particular scenarios. To devise these scenarios a working group of potential users has been formed. Publication of these results is scheduled for FY80.

Once the utility and validity of the ISEM prototype and the ISEM concept are assessed, the next questions that occur are: What are the appropriate levels of data aggregation? What is the appropriate level of model detail? What types of operating characteristics are required to provide meaningful answers to real world Air Force manpower and personnel problems? These will be answered by the ISEM sensitivity analysis which is investigating the effects of varying levels of model detail and aggregation. This consists of essentially two steps. First, the range of scenarios which ISEM should address will be assessed, and based upon that assessment, the variables will be manipulated and the interactions analyzed. Results will be published in FY80.

With the results of the ISEM Prototype Test and Evaluation research and the ISEM Sensitivity Analysis, it then becomes feasible to determine what the cost and benefits of an ISEM might be. This is the thrust of the third research effort. The ISEM Cost/Benefit Analysis will determine the cost and benefits of development. This will be a difficult task. First, review the methodologies and techniques for assessing the cost and benefit of large-scale simulations such as ISEM which produce non-market valued information. Then, perform the analysis. Results of research should also be published in FY80. Results from these research efforts will provide the basis for determining the feasibility of development of ISEM.

As a part of ISEM, AFHRL is also pursuing the development of a National Skills Market model. This research is being pursued somewhat independently since research in the National Skills Market has implications for many other potential users besides ISEM. Because of this, the National

Skills Market research and the ISEM research are conceptually separated in the AFHRL research program. However, all research in the National Skills Market is being coordinated to insure that the resulting product can support ISEM requirements for labor market data. The purpose of the National Skills Market model is to determine how the labor market affects the ability of the Air Force to recruit and retain required personnel. Presently the National Skills Market has been broken into two sections. First, research into the internal-external labor market interface will attempt to determine how people within the Air Force and potential recruits make their decisions to enter or leave the service. Then in the National Skills Market submodel, research will attempt to determine in which submarkets of the national labor market the Air Force competes, who the other competitors are, and what the market structure is.

In summary, ISEM offers substantial promise for providing Air Force decision makers with a new policy analysis tool of a fundamentally different type. While there are several important questions about ISEM that remain unanswered, research is underway to answer these questions so that a wise and prudent decision can be made on the full-scale development of ISEM.

Biographical Sketch

Captain Stanley B. Polk was born in Jackson, Mississippi on December 9, 1946. He graduated from Mississippi State University in 1970 receiving a BA degree. He was commissioned in the Air Force through AFROTC and entered active duty with an initial assignment to Minuteman Missile Operations at Malmstrom AFB, Montana. In 1973 he received an MBA from the University of Montana and was reassigned to Ballistic Missile Evaluation as a missile systems analyst at Headquarters Strategic Air Command. His work primarily involved the development and assessment of quantitative techniques for evaluating missile system accuracy and reliability from operational test and evaluation programs. In 1976 he became a candidate at the University of Nebraska for the PhD degree in management with emphasis in quantitative methods and organizational behavior. In 1976 he was reassigned to the Air Force Human Resources Laboratory where he has since worked in the Manpower and Personnel Systems Branch of the Occupation and Manpower Research Division. His research at the Laboratory has concentrated on developing a total systems simulation model of the Air Force Manpower and Personnel System for analyzing the expected systems impact of high-level policy options. His dissertation research is in the leadership area and is concerned with leader influence over subordinate decisions.

EVOKED BRAIN POTENTIALS AS PREDICTORS OF PERFORMANCE: HEMISPHERIC ASYMMETRY AS RELATED TO PILOT AND RADAR INTERCEPT OFFICER PERFORMANCE

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EVOKED BRAIN POTENTIALS AS PREDICTORS OF PERFORMANCE: HEMISPHERIC ASYMMETRY AS RELATED TO PILOT AND RADAR INTERCEPT OFFICER PERFORMANCE

Abstract

Training a single Navy pilot to combat readiness is estimated to cost about $500,000. Every year several aircraft, each costing millions of dollars, are lost in flight accidents. Improved pilot selection would reduce these costs.

A great deal of effort has been expended since World War I in the attempt to select, from the pool of applicants to flight training, those with the greatest potential for successful completion of training and for high level post-training performance. Despite intensive effort using paper and pencil tests, psychomotor tests, and other approaches, attrition in pilot training has averaged around 30% for the past several decades.

The present research was an exploratory study intended to determine the utility of a newly emerging technology--computer-averaged brain wave analysis--as a means of improving the selection of naval aviators. During the past decade, research in several laboratories has revealed surprising differences in the functions served by the left hemisphere (LH) and right hemisphere (RH) of the human brain. These studies used as subjects patients in whom it had been medically necessary to sever the bridge of nerve fibers linking the LH to the RH. The LH serves functions characterized as verbal, logical, and sequential. The RH processes information of a different kind, and in a different way--functions characterized as three-dimensional, simultaneous, judgmental, and intuitive. Our hypothesis was that these difficult-to-measure functions of the right hemisphere might be those especially important in aviator performance, and might be measured through the use of the new computer-averaged evoked potential technique.

Subjects were 28 Navy pilots and 30 radar intercept officers (RIOs) who volunteered to be tested. Eight channels of evoked potential data were gathered from scalp-contact electrodes. Statistical analysis showed consistent differences in brain wave measurements between pilots and RIOs, and within the pilot and RIO groups, between those rated as high performers vs those rated as low performers by their superior.

EVOKED BRAIN POTENTIALS AS PREDICTORS OF PERFORMANCE: HEMISPHERIC ASYMMETRY AS RELATED TO PILOT AND RADAR INTERCEPT OFFICER PERFORMANCE

Introduction

The personnel costs in naval aviation are extremely high. Training a single Navy pilot to the point of combat readiness is estimated to cost nearly $500,000. Attrition of pilots in training has averaged 30 percent during the past several decades. Even pilots who wash out early may represent a loss of several hundred thousand dollars. Further, human error is a significant cause of aircraft accidents, and results in the loss of a number of multi-million dollar aircraft each year. Improved aviator selection could reduce these costs.

Intensive attempts to devise methods for selecting, from the pool of applicants for flight training, those with the greatest potential for effective performance, first as trainees and later as pilots and other flying officers, have been carried out by the various military services for the past half century. By and large, these efforts have been reasonably successful--as successful as available technology would permit. A wide variety of paper and pencil tests, psychomotor tests, neurological tests, etc. have been experimentally evaluated. Despite rigorous efforts to improve aviator selection, it has not proven possible to reduce the attrition rate among trainees from its present level of approximately 30 percent.

Aviators represent a highly selected, highly elite group. Nevertheless, one can assert with confidence that there remains a wide range of ability not only among those who are selected for aviation training, but even among those who survive the training and become full-fledged combat aviators.

Most of us vastly underestimate the range of human abilities. Whenever it has been possible to measure any dimension in which humans vary--whether that dimension has been physical, chemical or behavioral--the range of variation has been truly enormous. For example, in some of the studies conducted by industrial psychologists, production supervisors have been asked to estimate the range of differences in performance between the most and least productive of their experienced workers. Their estimates usually range from about 10-30 percent, that is, they say the better workers are perhaps 30 percent more effective than the least productive employees. Yet, when actual "hard"

production figures are gathered, even for such simple tasks as typing, card punching and machine sewing, results show that the productivity differences usually range from 200-300 percent. As the difficulty and complexity of the task increase, the range increases. For example, a study of the time taken by computer programmers to complete a standard program showed a range difference of 2300 percent. No doubt "hard" measures of military combat pilot performance would yield equally large differences in performance.

How can we measure or predict these individual differences in such a way as to permit us to select from a group of applicants those most likely to turn out to be the best performers?

A recent review titled "Aviator Selection 1919-1977," published by the Naval Aerospace Medical Research Laboratory lists 145 items in its bibliography, describing a truly enormous range of bright ideas that psychologists and others have generated during a half century of concentration on the problem. The authors of the Aerospace Medical Lab report observe that despite all the research, "current selection tests normally account for less than half of the total variance associated with aviator success in training." They also comment, "...lack of any prominent breakthrough... since the war years (WW-II) suggests that non-paper and pencil performance tests should be investigated more fully..."

Psychobiological Approach to Selection

The past ten years have produced some extremely interesting developments in the field of psychobiology--developments that may lead to major improvements in personnel selection technology.

The first of these developments concerns the availability of new, highly sophisticated electronic devices for recording, amplifying and analyzing complex bioelectrical signals, such as those which emanate from the human brain. The evoked potential technique is now being investigated in many laboratories around the world. Evoked potentials (EPs) are minute electrical brain waves which are produced by sensory stimulation. They are ordinarily obscured by larger amplitude ongoing electroencephalographic (EEG) activity. Advances in electronics and computer design permit the recording and measurement of EPs with a high degree of accuracy and reliability. The use of the computer to record and average the EP so that it may be seen against the background noise

of the EEG has provided a dramatic upsurge of interest in the field of psychobiology.

The other major development in the field of psychobiology stems from our newly emerging understanding of the different functions of the right and left hemispheres of the brain. These findings are an outgrowth of the attempt to treat severe incapacitating epilepsy by surgically severing the corpus callosum--the bridge of nerve fibers that connects the two hemispheres. Research on patients on whom such surgery was necessary has revealed surprising differences between the information processing functions of the two halves of the brain. Briefly, the function of the dominant hemisphere (the left for most people) is to process verbal, logical,"rational" information in a sequential, linear fashion. The function of the other hemisphere (the right hemisphere in most people), which has been described as spatial, non-linear, simultaneous, judgmental, holistic and intuitive, is not as yet well-defined. Actually, of course, virtually all tasks require the use of both hemispheres. However, when you look at a photograph of a crowd and try to pick out the faces of the people you know, your judgmental right hemisphere is working harder. When you compose a letter, solve an equation, or answer a multiple choice question, your logical left brain bears most of the load.

An analysis of Einstein's writings has led some researchers to conclude he solved problems by a brilliant creative visualization of the solution (probably right hemisphere), then followed with a meticulous, painstaking (left hemisphere) mathematical proof.

Actually, the discovery of the differing functions of the right/left hemisphere of the brain has been anticipated for a long time, primarily by writers and philosophers. Figure 1, taken from Robert Ornstein's book, The Psychology of Consciousness, shows the variety of proposals that have been made by various writers which contrast what Ornstein refers to as "the two modes of consciousness." The middle column shows the many terms which we may use in helping to describe left hemisphere function, while the right column helps better understand the kinds of concepts which have been applied to right hemisphere function.

Figure 2, also taken from Ornstein's book, shows the responses from a split-brain patient to the request that he write the word "Sunday" and copy two figures; a cross,

THE TWO MODES OF CONSCIOUSNESS: A TENTATIVE DICHOTOMY

Who Proposed It?	Left Hemisphere	Right Hemisphere
Many sources	Day	Night
Blackburn	Intellectual	Sensuous
Oppenheimer	Time, History	Eternity, Timelessness
Polanyi	Explicit	Tacit
Levy, Sperry	Analytic	Gestalt
Bogen	Propositional	Appositional
Lee	Lineal	Nonlineal
Luria	Sequential	Simultaneous
Semmes	Focal	Diffuse
I Ching	The Creative: heaven, masculine, yang	The Receptive: earth, feminine, yin
Many sources	Verbal	Spatial
Many sources	Intellectual	Intuitive
Vedanta	Buddhi	Manas
Jung	Causal	Synchronicity
Bacon	Argument	Experience

Figure 1. Concepts relating to hemispheric function (per Ornstein).

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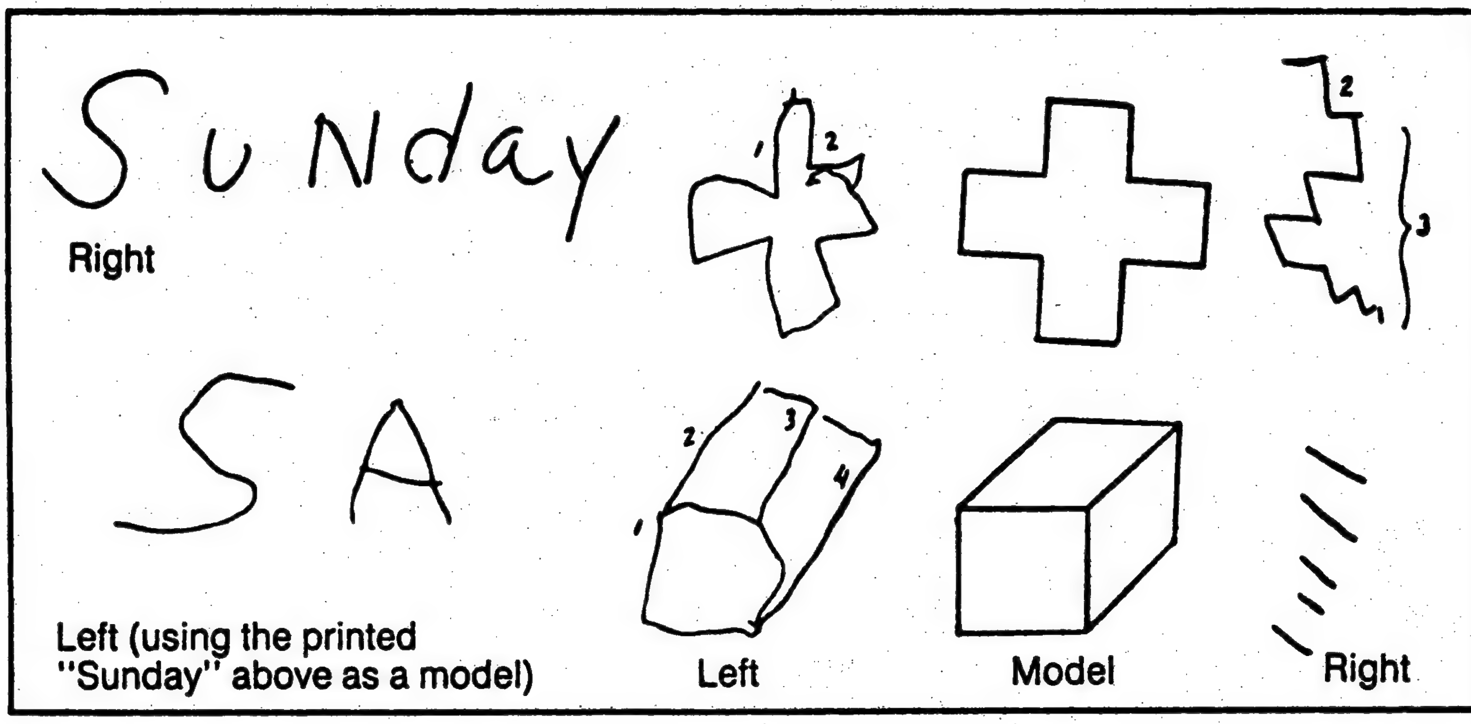

Figure 2 The response of a split-brain patient to the request to write *Sunday* and to copy the two figures.

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and a cube. With his right hand, which is primarily driven by the left hemisphere, the subject was able to process verbal material. As you can see, he can write the word "Sunday." However, as you can also see, he was totally unable to copy the cross or the cube. With his left hand, however, he was unable to cope with the verbal demand to write the word "Sunday," but he did a recognizable job of copying the cross and the cube.

How do these findings from the field of psychobiology relate to the problem of aviator selection, or for that matter, the selection of personnel for any type of training or duty? Most testing for personnel screening and assignment to training, whether in the military or civilian sectors, is based on paper and pencil tests. Such tests do a fair to good job of identifying those who will succeed in school-type settings, such as civilian schools and colleges, and military training. Unfortunately, however, paper and pencil tests leave much to be desired in predicting successful <u>on-job</u> performance. Psychologists have been butting their heads against this stone wall for well over half a century.

In my first 20 years of doing personnel measurement research for the Navy, I constructed and evaluated perhaps 50 different paper and pencil tests, most of these specifically designed to predict success in real-life, as opposed to academic, settings. After the 50th failure, I thought it might be time to try a new tack.

A few years ago I concluded, from avocational reading in the field of psychobiology, that despite the efforts by myself and others to predict performance in non-classroom situations, the tests we were developing were primarily aimed at what was beginning to be called left hemisphere function. It seemed however, that perhaps we should be aiming at the other half of the brain--an elusive target. Evoked potential technology, it seemed to me, might be a way of getting at the prediction of the hard-to-characterize, practical, real-life behaviors which determine how well people do in real jobs, such as piloting airplanes or operating sonar gear. With these ideas in mind (both hemispheres), we embarked on a program of exploratory research. We have completed several studies so far, including one on reading-disabled recruits, and another on sonar operator performance.

Hemispheric Asymmetry in Aviators

The present study was intended to determine whether psychobiological, specifically evoked potential, technology might provide information about individual differences in brain function which would allow us to make predictions about the performance of naval aviators. We were particularly interested in the possibility that those men showing larger brain wave amplitudes in their right hemispheres than in their left might prove to be better prospects for being successful pilots than men showing the opposite pattern. These differences in amplitude between the right and left hemisphere are referred to as "hemispheric asymmetry." In the case of the pilot, there is a great demand that he be able to operate effectively in three-dimensional space, and to make split-second judgments by weighing a number of disparate variables essentially simultaneously. These demands seem to place a great burden on the right hemisphere.

We also hypothesized that radar intercept officers (RIOs) might be found to show the opposite configuration of hemispheric amplitude. RIOs, while they certainly must have a good deal of three-dimensional imagination and must think quickly, are required to perform operations in a logical, sequential, orderly manner to function effectively.

Obviously, pilots must have both hemispheres functioning at a high level to be effective pilots, and the same is true of RIOs. Our hypothesis, then, was that while both hemispheres must be functioning effectively in both pilots and RIOs (insofar as our instrumentation would permit us to make such judgments), pilots would show greater asymmetry in favor of the right hemisphere, while RIOs would show relatively greater asymmetry favoring the left hemisphere. We assumed that these differences, if found, would be the result of the selection and attrition pressures, self-initiated and imposed from without, which impinge differentially upon pilots and RIOs.

We also generated a hypothesis regarding aviator proficiency. We predicted that within the pilot group, the pilots who were regarded as being superior performers would show more right minus left asymmetry than the lower rated flyers, whereas the opposite would be true among RIOs.

Data Collection

The subjects in our study were 28 pilots and 30 RIOs assigned to a Readiness Training Squadron at the Miramar Naval Air Station in San Diego. Approximately half of each group were instructors and the other half students. We explained

the purpose of the study to the subjects and obtained their permission to test them. Although participation was voluntary, all the subjects were interested in the experiment and cooperated willingly.

The testing took place in the mobile NPRDC experimental van, which we were permitted to park in the squadron hangar. Figure 3 shows the van parked, ready for the testing to begin.

Figure 4 shows our testing setup. Note the cloth helmet with the eight electrode tubes attached, which was worn by each of the subjects during testing. Sponge-tipped electrodes, moistened with an electrolytic solution, were placed in each of the electrode tubes, in contact with the subject's scalp. Leads from these electrodes were wired to our instrumentation package.

Data were analyzed on our Data General NOVA computer system. The system has a dual drive floppy disk, a custom 8-channel integrated amplifier and filter network and an alpha-numeric oscilloscope monitor. We have since upgraded and supplemented this equipment considerably, and now our laboratory has what we consider to be one of the most advanced packages of hard- and software evoked potential instrumentation available anywhere. The setup that we used for our aviator study now seems somewhat primitive by comparison, yet the results we got were quite interesting and quite promising.

Figure 5 shows the computer output for a single subject. Actually, our upgraded NOVA system now produces a much more sophisticated and informative readout, but Figure 5 shows the output as gathered during the aviator study.

The brain waves were gathered while the subject was stimulated by a series of 100 light flashes. Because the stimulus is a visual one, these brain waves are referred to as visual evoked potentials. For each of the eight electrode sites, we have the averaged wave form for both the first 50 flashes and the second 50 flashes (to provide a measure of habituation). We also have recorded, to the side of each wave form, the microvolt root mean square measure of amplitude for the first 50 flashes (top) and the second 50 flashes (bottom). On the left hand side of the figure you see the various readings for the left hemisphere, on the right, for the right hemisphere. The top two recordings are for the frontal region of the brain; the second line across is for the central region of the brain, left and right hemisphere respectively. On the third line across are the data for the parietal region of the brain, and

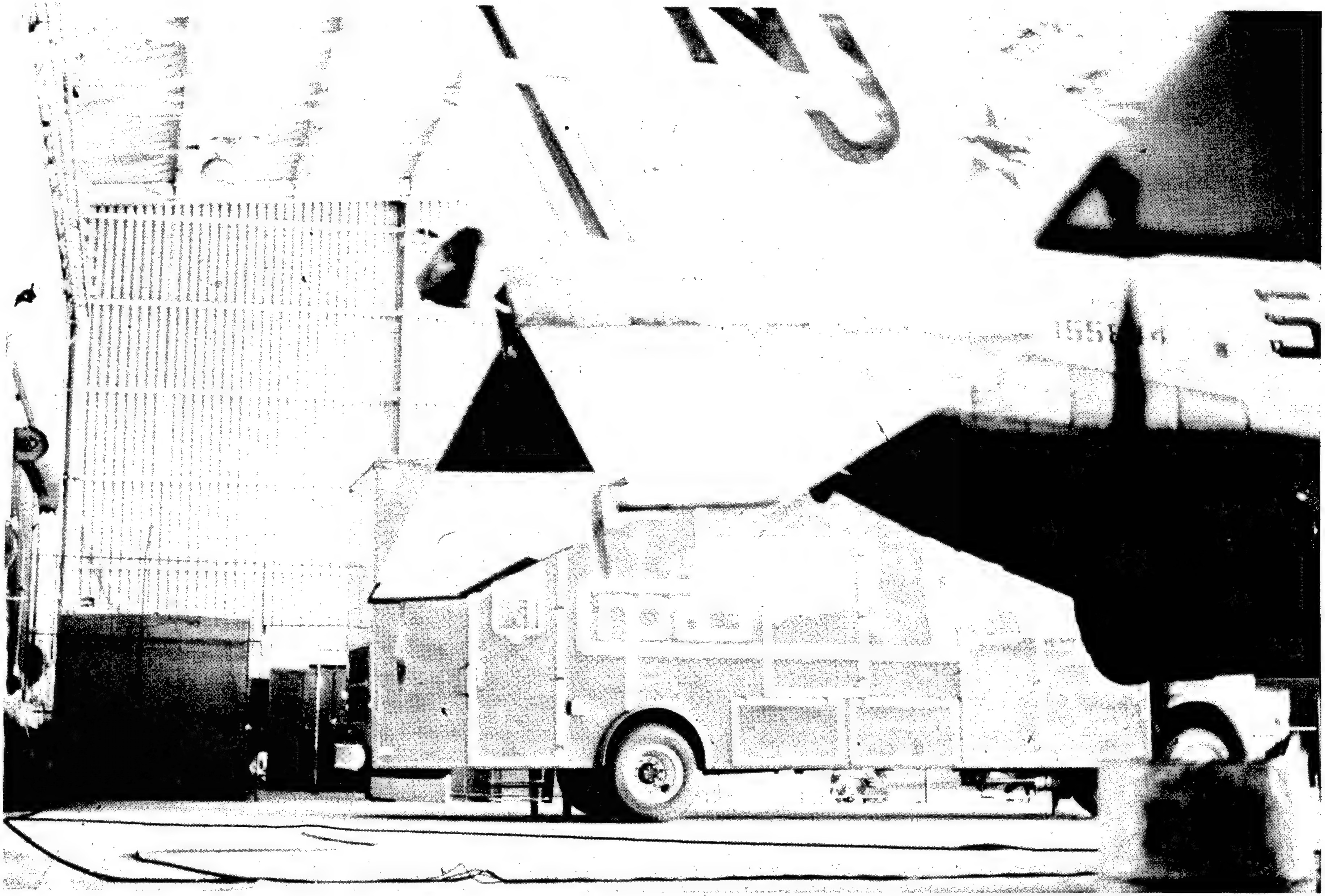

Figure 3. NPRDC testing van in F-4 hangar. 1851

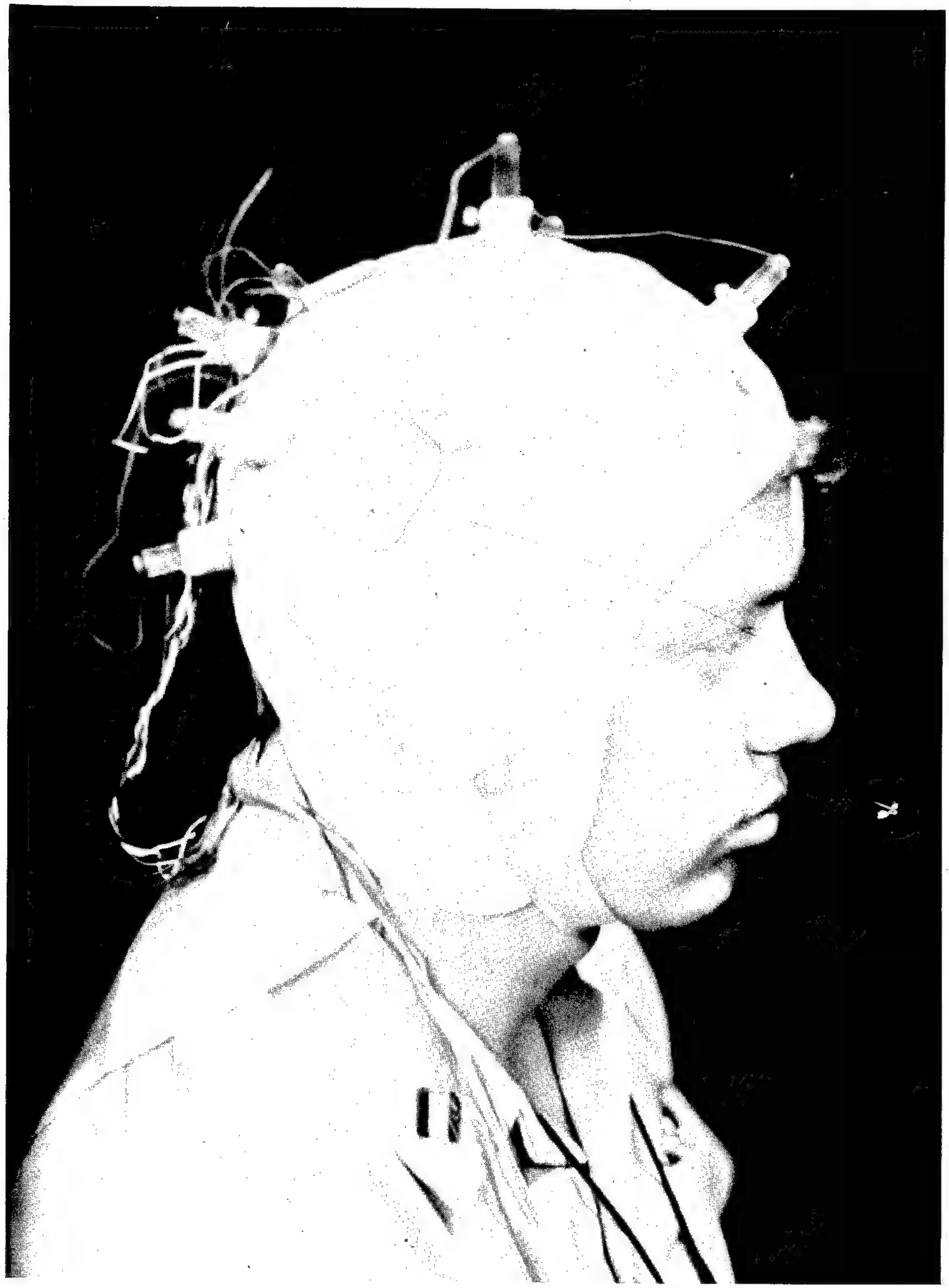

Figure 4. Subject wearing Lycra electrode helmet.

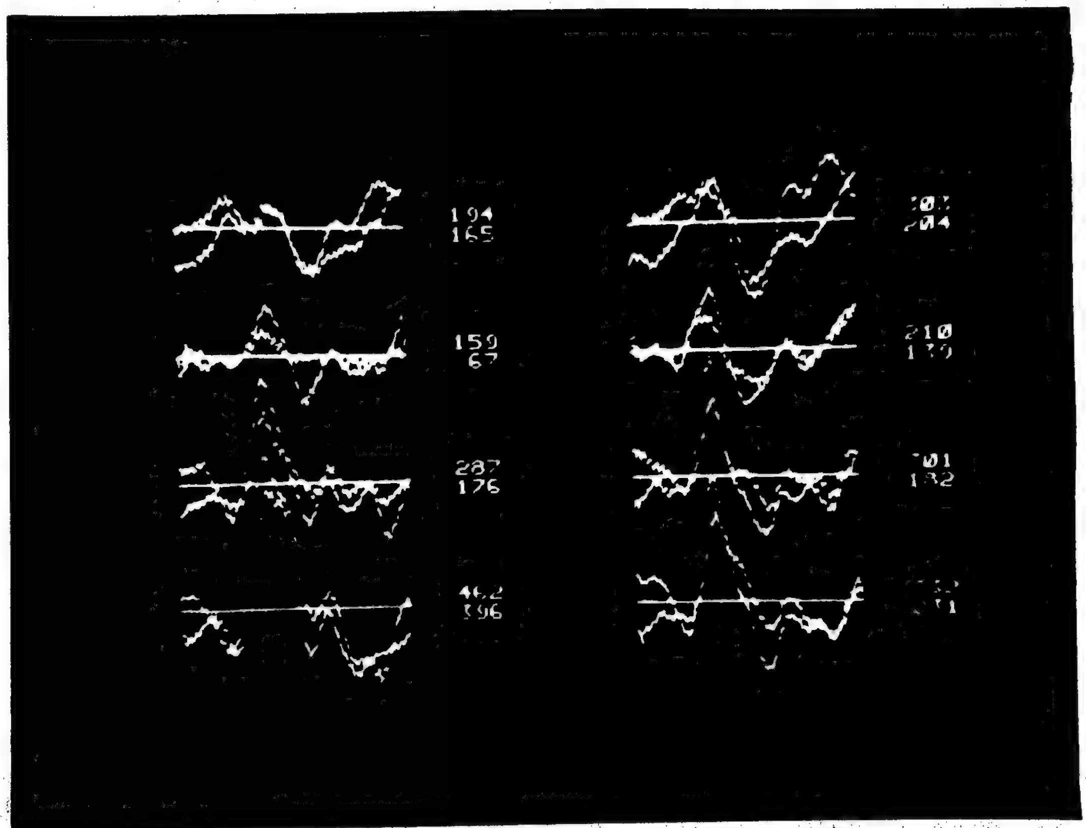

Figure 5. Evoked potential recordings from eight electrode sites.

finally at the bottom are the data for the occipital electrodes, that is, from readings taken from the scalp at the back of the head.

We asked the operations officer of the squadron, who was well acquainted with the proficiency level of the men, to provide us with a rating, on a 10 point scale, of how proficient each subject was considered to be. The ratings ranged from 7-10 for the instructors and from 6-9 for the students. We had decided that our initial analyses would assume that each individual's EP characteristics were the result of his aptitudes, not of his experiences, so we added 1 point to the scores of each of the students to correct for what we assumed to be a decrement due to lack of experience.

Results

Obviously, we have collected a massive amount of information and it would take too long to present and describe the findings in any detail. For present purposes, I will restrict the analysis to two major questions of interest. (1) Are we able to discriminate the pilot and RIO groups on the basis of their evoked potentials? (2) Do pilots and RIOs differ in terms of hemispheric asymmetry, and if so, are the differences more pronounced for those pilots and RIOs rated as superior performers than for pilots and RIOs who were given low performance ratings?

With regard to the first question, on the group differences between pilots and RIOs, Figure 6 presents the means and standard deviations of the EP amplitudes measured at four sites on the left hemisphere. As you can see, the pilots were more variable in their amplitudes, and also had greater mean amplitudes, then did the RIOs, at each of the four electrode positions. The right hemisphere (Figure 7) data showed essentially similar findings. In no case was the standard deviation or the mean amplitude for the RIO group greater than for the pilot group.

Figure 8 is a scatter plot with EP amplitudes from the left frontal region on one axis and EP amplitudes from the left central region of the brain on the other axis. These variates were determined by discriminant analysis. The discrimination line, which was drawn in visually to fit these data, suggests that one might be able to predict with a fairly high degree of accuracy whether a given individual is a pilot or a RIO from his brain wave recordings. Of course,

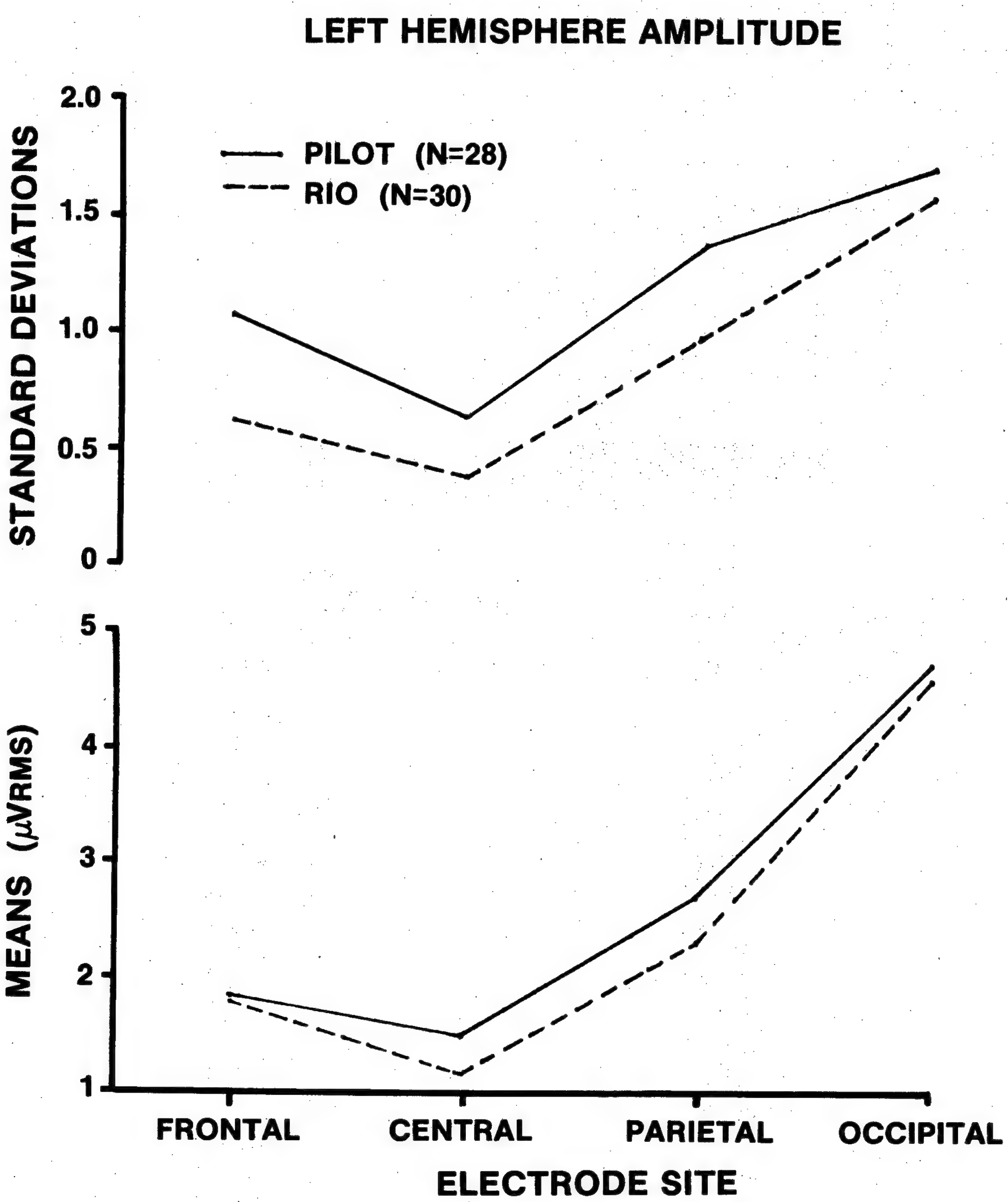

Figure 6. LEFT HEMISPHERE MEANS AND STANDARD DEVIATIONS AT EACH SITE

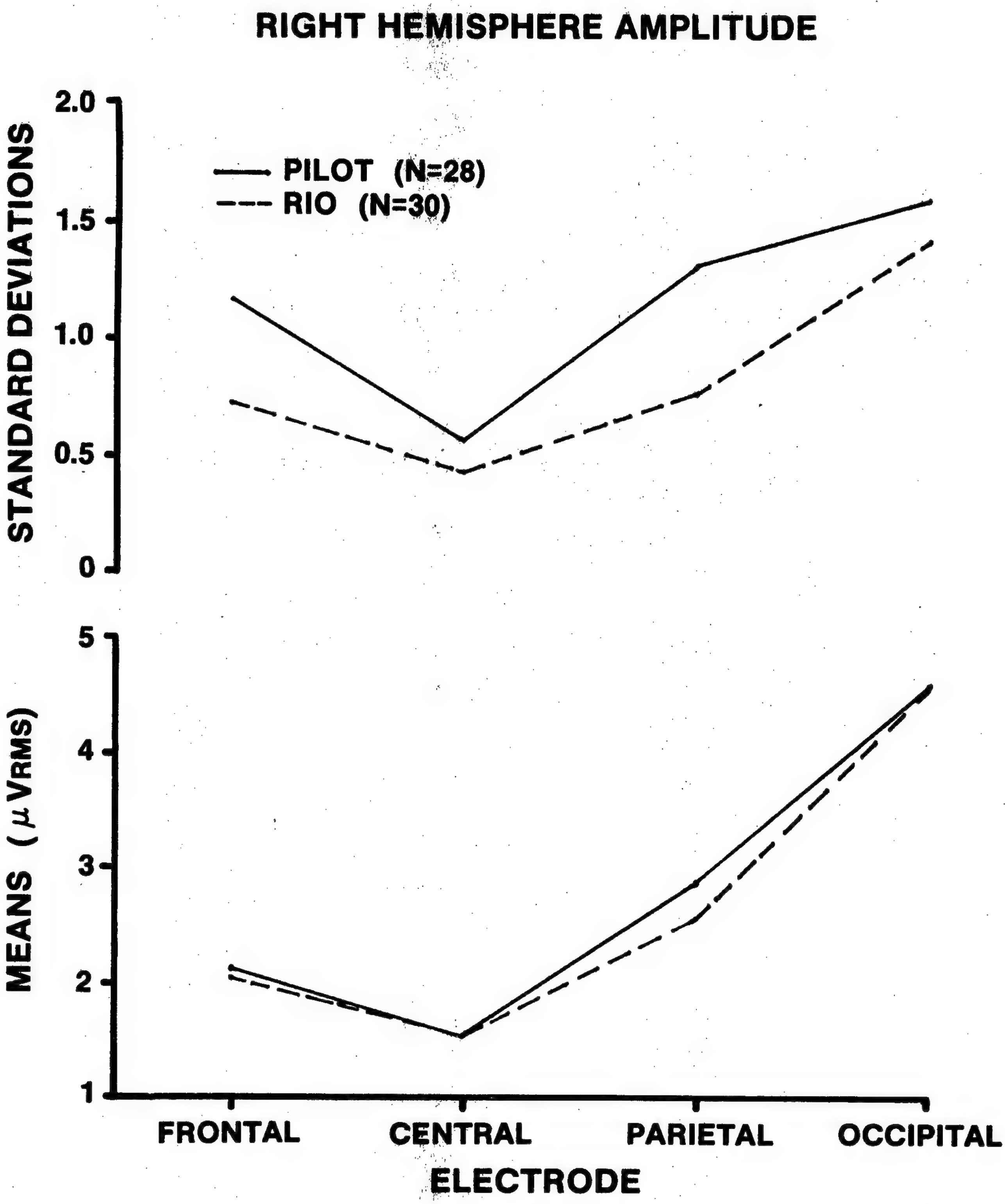

Figure 7. **RIGHT HEMISPHERE MEANS AND STANDARD DEVIATIONS AT EACH SITE**

1856

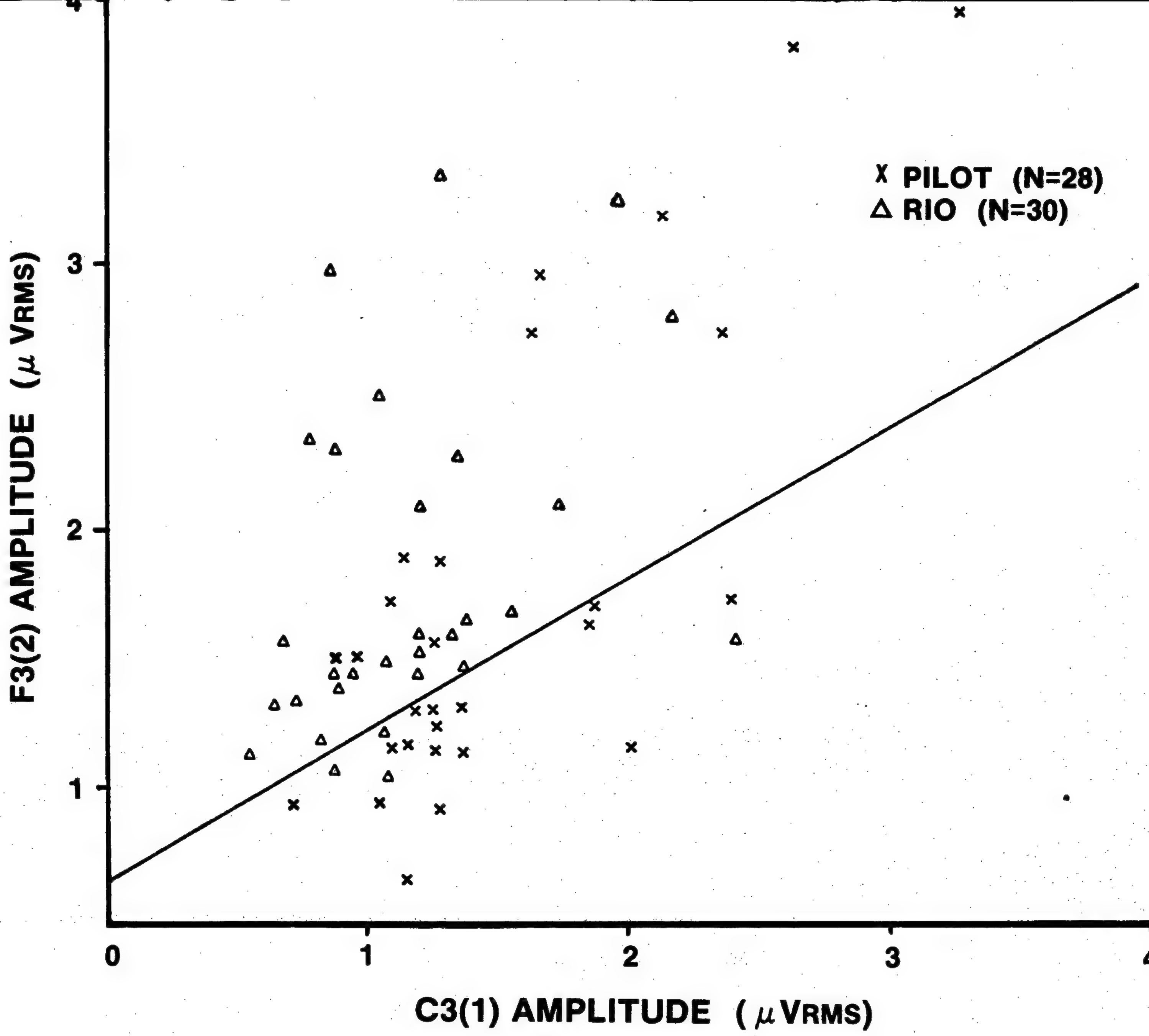

Figure 8. SCATTERPLOT SHOWING SEPARATION OF PILOTS AND RIOS

1857

these findings will have to be cross-validated on another sample before we could have much reliance in them. Frankly, the degree to which pilots and RIOs can be separated by their evoked potentials is rather surprising to us. It did not seem to us, from what we were able to learn about the procedures for selecting and assigning pilots and RIOs, that there would be so much difference in the evoked potentials of the two groups. (Further analysis suggests that part, but not all, of the differences may result from differing cognitive demands upon pilots and RIOs. The data are being reanalyzed to examine that question).

Next, we tested the hypothesis that the cerebral asymmetry of pilots and RIOs would differ, and that asymmetry would be related to the differences in performance ratings <u>within</u> each group. (I might add that in making these analyses, we omitted the subjects who were left handed because left-handed people sometimes have reversed dominance).

As you can see from Figure 9, our hypothesis seemed to be relatively well-confirmed. All of the high performing pilots, those rated 10, had right hemisphere amplitude greater than left hemisphere amplitude, and the percentage decreased as the performance ratings decreased. Exactly the opposite was true for RIOs.

So far, we have discussed only lateral asymmetry--the right-left distinction. We have also explored front to back asymmetry, with some interesting results, as presented in Figure 10. Figure 10 is a bit complicated, dealing as it does, with three variables. Looking at the data for pilots, we see that the high performing men showed less variation in their EP asymmetry than the low performing men, and that this difference in variability was strikingly more pronounced in the electrode sites at the back of the head (visual area) than the front. The same pattern is seen for RIOs, and also for a group of 28 antisubmarine warfare (ASW) trainees on whom we obtained similar data as part of another study.

<u>Discussion</u>

The above analyses are, of course, based on rather small samples. In the case of the discriminant analysis, we know that the positive findings we report are affected by capitalization on chance. The data set was too small to permit division into the usual training and testing subpopulations. However, as indicated earlier, this was intended to be merely an exploratory study, designed to try out our gear, to see how effectively

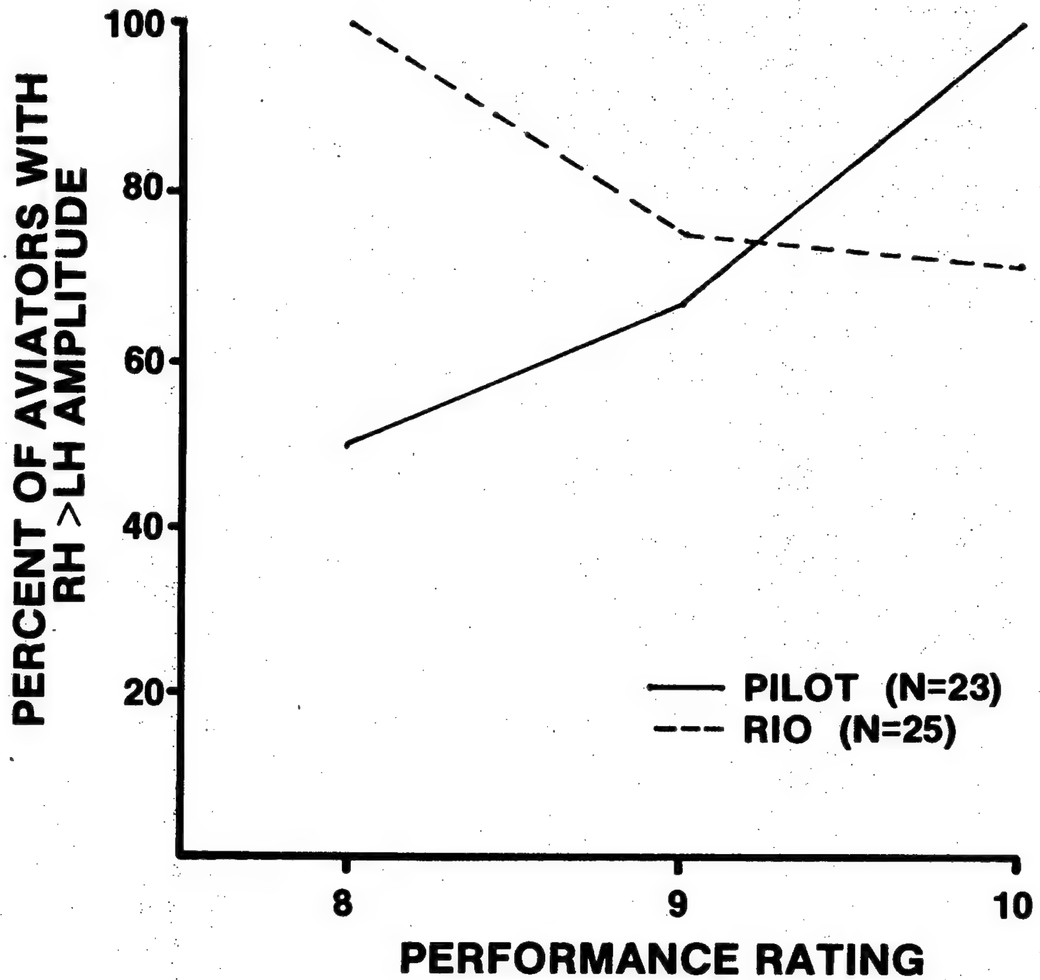

Figure 9. **ASYMMETRY AND PERFORMANCE RATING**

1859

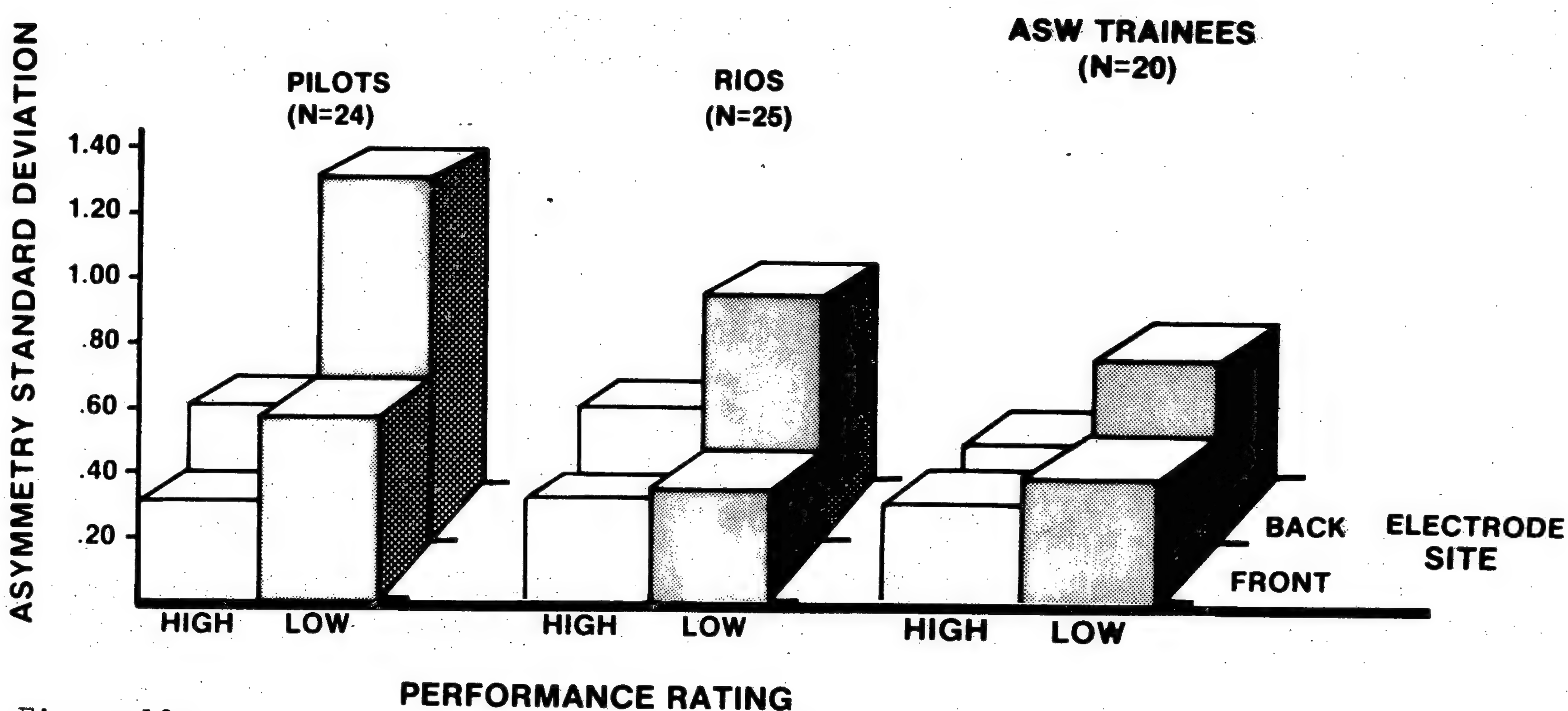

Figure 10:
ASYMMETRY STANDARD DEVIATION PERFORMANCE RATING AND ELECTRODE SITE

1860

our equipment would work in a field situation, and to test out some hypotheses that we hope later to test in a more formal way on a considerably larger sample.

Additionally, we are keenly interested in finding if our results can be confirmed in an unrestricted sample of trainees, before those with the lowest aptitude are eliminated, and before Navy training and experience can affect the results.

We are only beginning to investigate the application of psychobiological technology to the problem of improving personnel selection and training, but so far, we have been encouraged by what we have found.

Biographical Sketch

Bernard Rimland was born in Cleveland Ohio on November 15, 1928. He received a B.A. in 1950 and an M.A. in 1952, both in psychology, from San Diego State University. He received his Ph.D. in experimental psychology from Penn State University in 1953. His dissertation study was an experimental evaluation of several variables (e.g., camera angle, information density) which affect the rate at which Navy recruits learn from training films.

In December 1953, he was appointed to the Navy Personnel Research Activity (now Navy Personnel Research and Development Center) San Diego, as a measurement research psychologist and has been employed at NPRDC since then. In 1964/65, Dr Rimland was awarded a Ford Foundation Fellowship at the Center for Advanced Study in the Behavioral Sciences at Stanford. His work has centered around the measurement of individual differences in abilities and interests, first through the use of traditional paper and pencil tests, and more recently, through the use of psychobiological techniques, such as the cortical evoked potential. He is currently Senior Scientist and Director of Special Projects at NPRDC. He is the author of nearly 100 scientific and technical publications and serves as an officer or advisory board member for a number of scientific and professional organizations.

Gregory W. Lewis was born in Seattle, Washington on March 3, 1940. He received his B.S. degree in 1962, his M.A. degree in 1965 and his Ph.D. in 1970 from Washington State University. He was a participant in the U.S. Army Graduate Student Program, Washington State University (1967-1970). His participation in research expeditions included trips to: Pt. Barrow and Barrow (1968 and 1969); Holloman Air Force Base, New Mexico (1967 and 1968); Primate Research Centers in Washington and Oregon (1967-1969). From 1970-1974 he was a research psychophysiologist at the U.S. Army Medical Research Laboratory, Fort Knox, Kentucky.

In 1974 he was employed by the Navy Personnel Research and Development Center, San Diego, California as a research psychophysiologist (his current position). His research interests include: psychophysiology and individual differences; electrophysiological and neurophysiological correlates of behavior, particularly the visual system; and brain function modeling. He directs the NPRDC Psychobiology Research Laboratory. He is a member of several professional and honorary societies and the author of approximately twenty-five publications.

LAUNCH OPPORTUNITY FOR AIR-TO-GROUND, VISUALLY DELIVERED WEAPONS

by

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Launch Opportunity for Air-to-Ground, Visually Delivered Weapons

Abstract

This paper presents a method for computing the probability of an aircrew being able to visually locate a ground target and launch a weapon against it. The major factors used in the computations are target acquisition performance, aircraft maneuvering requirements, terrain masking, visibility, and weapon operating time. Estimates of these factors are based on real-world data whenever possible, as opposed to mathematical modeling. The algorithm used to combine these factors is described and sample results are presented. The results show that the probability of releasing or launching a weapon on a target is quite low in many situations.

I. Introduction

Most air-to-ground weapons currently in use require that the aircrew make a visual acquisition of the target before the weapon can be employed. Such weapons include bombs, guns, rockets, and guided missiles. The choice of tactics and weapons, and the estimation of the effectiveness of the weapons is currently based upon delivery accuracy and weapons (warhead) effectiveness on specific targets. The probability of finding the target in time to convert to an attack and launch the weapon almost always is ignored.

This paper presents a method for computing the probability of an aircrew being able to visually locate a target, convert to an attack pass, and launch, release, or fire a weapon against the target; example results are also given.

A. Objective

The algorithm described here was developed to make it possible to estimate the probability of successfully making a first-pass attack on a ground target with a fixed-wing, high-speed aircraft. The probability that is calculated describes the estimated frequency of use, or *utility*, of a given aircraft/weapon system combination.

Some example questions that might be answered by this probability calculation (or measure of utility) are:

1. What percent of a large number of first-pass attacks would be successful against a column of tanks moving in European terrain during the day in June?

2. How often can we expect to successfully employ a gun, a missile, or a bomb against three tanks in a group in the desert in December?

B. Limitations

In addition to the limitation of the algorithm to the utility aspect of weapon delivery, there are other limitations to the algorithm in its present form. These are:

1. The algorithm is limited to weapon delivery by high-speed, fixed-wing aircraft. This limitation is present because the data used in the algorithm were collected

in field tests using such aircraft. Extrapolation to other conditions (e.g., helicopters with a pop-up maneuver) would be risky.

2. The algorithm is limited to weapon delivery involving limited maneuvers by the delivering aircraft. Generally, the data used in the algorithm are derived from straight and level flights toward the target area; pop-ups or roll-ins from high altitude are not included in the calculations. The algorithm best describes the low-level, high-speed delivery tactic.

3. Only a subjective estimate has been made on the limits on the parameters that should be used. These estimates can serve as a guideline to the user, however. They are:

Aircraft altitude - 500 to 2500 feet
Aircraft speed - 350 to 550 knots

II. Method

The basic approach used in the development of the algorithm was to use empirical data as much as possible. A means was devised to combine this empirical data, complement it with theoretical calculations when required, and calculate the desired result.

The reliance on empirical data was preferred since it was felt that such data is more representative of the real world than theoretical calculations. Hence, actual ground survey data produced from optical measurements made in the field was preferred to map study results for the computation of a clear line of sight (CLOS). Field test results giving visual detection ranges of ground targets by pilots were used instead of a sophisticated mathematical model of the geometry and the visual search process.

The method in which the data are combined in the algorithm is shown in Figure 1. The time required to operate the weapon system and how the aircraft will be flown are used to calculate the *Required Range*. This range is the range by which the pilot *must* visually detect the target in order to be able to make a first-pass attack. If the pilot detects the target beyond this required range, he will be able to make the attack; if he detects the target closer than the required range, he will not be able to attack on that pass.

Some general rules have been derived from actual field test data for computing the probability of visually detecting the target. The computation is in the form of a cumulative probability as a function of range from the target. The cumulative probability function is then combined with the required range to produce the probability of acquisition *by* the required range.

The last procedure in the algorithm is to combine the acquisition probability with the distribution of unmask ranges and visibility ranges actually expected to occur in the region of interest. Ceiling data can also be used to estimate the percent of the time that particular altitudes could be flown.

This last procedure produces the final output of the algorithm: the expected proportion of the time that a given target can be successfully attacked under a set of specific conditions.

A. Aircraft Flight Parameters

The delivery tactics are, in part, determined by the weapon characteristics. The use of free-fall bombs, guns, or unguided missiles requires that the aircraft be flown directly toward the target. Other weapons with some off-boresight capability have also been used principally in the straight-ahead delivery mode.

Unless exact navigation, or target cueing, is available, most targets should be expected to appear somewhere off the dead-ahead direction. In these cases, the pilot will be required to turn the aircraft toward the target before preparing for weapon release. The geometry describing the entire attack process is shown in Figure 2.

The range required to make the attack decision and roll the aircraft is designated A in Figure 2(c). After the turn is complete, the aircraft must be rolled level, the weapon must be readied for launch, and launched some minimum range from the target. These events are included in the straight segment, B, in Figure 2(c).

From the geometry of Figure 2(c) one can show that

$$R_{RQ} = (A \cos \alpha + r \sin \alpha) \pm [(A \cos \alpha + r \sin \alpha)^2 - (A^2 - B^2]^{1/2} \qquad (1)$$

The turning radius of an aircraft is given by

$$r = \frac{V^2}{g\sqrt{n^2 - 1}} \qquad (2)$$

where g is the gravitational constant. Other substitutions that can be made in Equation 1 are related to the terms discussed above.

The factors discussed above can be included in Equation 1 by substituting

$$A = V(T_D + T_{RI}) \qquad (3)$$

where

R_D = decision-to-attack time
T_{RI} = time required to roll the aircraft into the turn

and

$$B = V(T_{RO} + T_{OP}) + R_{MIN} \qquad (4)$$

where

R_{RO} = time required to roll out
T_{OP} = operating time of the weapon
R_{MIN} = minimum release range.

The weapon operating time, T_{OP} given in Equation 4, is determined by the weapon system characteristics, the aircrew's capabilities, and the environmental operating conditions. Operating times can simply be assumed, derived from manned simulation tests, or from flight tests. The times have been found to vary from 2 sec. to as much as 12 sec.

The examples of operating times found in the literature illustrate the wide range of times that might be required with different aircraft systems. Another factor

that might affect these times is the size of the crew; it is thought that a single pilot would require more time to operate a complicated weapon system than an aircrew of two. The pilot must operate the system as well as fly the aircraft.

1. Angle-Off

The distribution of angle-off is a function of the accuracy of the intelligence information, the aircraft's navigation system, the target's mobility, availability of external target designation (e.g., forward air controller), and many other variables. No data sources have been located to date that could be used to derive angle-off distributions, so assumptions must be made if a distribution is used. Suffice it to say that use of the algorithm does not require the assumption that the target will always appear straight ahead of the aircraft.

2. Flexibility in Required Range Computation

The parameters in the computation have been named: T_{RI} is called roll-in time, T_D is decision time, etc. Other sequences of operation may require other events to occur, and the formulation given in Equation 1 can be used by setting some values to zero and/or changing the names of events. As long as the situation of interest has a straight-line segment, a curve representing the turning aircraft and another straight-line segment, Equation 1 can be used.

B. Visual Target Acquisition

The next step in the algorithm is the computation of the probability that the pilot will see the target as he flies toward the target area. The result is a cumulative probability as a function of range, for a given target/background combination.

1. Background

Two separate study efforts led to the development of the technique for computing acquisition probability: evaluation of mathematical models and summary of field test data. The model evaluation effort illustrated that there are often large differences among the many models that have been developed. It also showed that the models have not often been validated by field tests, so that one does not

know which of the models is the best predictor of target acquisition performance.

The summary of field test data provided a description of over 45 field tests of target acquisition and sample results of the tests. This tabulation of results illustrated that some actual test data were available for use in making performance predictions.

The result of this effort is a comparatively simple model for computing target acquisition performance. The model is really a data fit, and is based upon actual field test data.

2. Target Acquisition Definition

The definitions of target detection, identification, recognition, classification, and acquisition have been discussed and given in many, many reports on the subject. This simplified model is based on data from different field tests, where performance measures were not accurately defined. The target acquisition response seemed to be "I see the target," or "I have the target in sight." It seemed to be the point at which the pilot saw enough, or had enough information, to be willing to begin an attack pass on the object. This very general definition is the one used in the simplified model.

3. Target Acquisition Probability

The computation procedure uses subjective estimates of the visual appearance of the target as well as physical measurements (or estimates) of the target size, masking, and visibility.

The conspicuousness characteristic of the target is expressed in two ways: "contrastiness" and "associated pattern." The contrastiness of the target is the visual contrast between the most significant, distinctive, target-related feature and its background. The contrasting element may be the target object itself, or a distinctive associated feature.

The associated pattern is the target-related pattern in the target area. The pattern may be made up of target elements (e.g., a straight row of trucks) or of other elements (roads, a river) that can be associated with the target.

The maximum probability of target acquisition is taken from Table 1 as a function of the estimates of contrastiness and pattern.

TABLE 1. Maximum Sighting Probability, P_{MAX}.

Pattern	Contrastiness		
	High	Medium	Low
Large	1.00	0.75	0.50
Medium	0.75	0.56	0.37
Small	0.50	0.37	0.25

4. Target Acquisition Range

The probability of acquiring the target as a function of range is assumed to be related to the point at which the target becomes optically available. The point at which the target is unmasked to the observer (where a clear line-of-sight exists) and the meteorological range (visibility) are the major variables.

The rules of thumb that were derived from flight test data are as follows:

a. The median range of acquisition will occur at one-half the unmask range, or one-half the meteorological range, whichever is smaller.

b. The probability of acquisition will be 0.2 and 0.8 of the value taken from Table 2 at 0.625 and 0.375, respectively, of the unmask range or meteorological range, whichever is smaller.

These rules of thumb make it possible to construct a curve similar to that shown in Figure 3.

The algorithm uses the equation

$$R_{ACQ} = P_{MAX}\, e^{-\left(\frac{R_{RQ}}{R_A - 0.75\, R_{RQ}}\right)^2} \qquad (5)$$

to fit the curve, where

P_{ACQ} = probability of acquisition

P_{MAX} = maximum probability taken from Table 1

R_{RQ} = required range (Equation 1)

R_A = meteorological range of unmask range.

Equation 5 and the curve shown in Figure 3 are functions of the unmask range or the meteorological range (visibility). At this point in the computation process, the probability curves are generated for specific distributions or values of target type, weapon type (operating time), aircraft velocity, and initial target angle-off. It remains to modify the calculations by the unmask and visibility data actually expected in the area of interest.

C. Masking, Ceiling, and Visibility Data

The environmental data included in the algorithm tie the probability of launch calculation to a specific time and place by using representative masking and visibility data. The data are used to weight the probability calculation made by Equation 3 by the expected frequency of occurrence of masking, visibility, and ceiling values.

1. Masking

The masking data used in the algorithm were produced by an actual ground survey, and include both terrain and vegetation effects. These data are stored in the algorithm and used to compute probability of unmask for whatever range and aircraft altitude the user chooses. The computer file contains an element for each terrain type; designation of the code name causes the appropriate masking data to be used in the computation. The user may also use other masking data, provided such data are in the form of mask angles and ranges to masking objects.

2. Visibility and Ceiling

Weather data from the USAF Environmental Technical Applications Center (ETAC) have been found to be the most comprehensive source for algorithm use. The data

are usually in the form of cumulative probability curves that show the probability that visibility is equal to or greater than any given value, or that ceiling is at least as high as a given altitude.

3. Use of the Data

The algorithm converts these cumulative curves into discrete distributions of probability. The discrete probabilities are then each multiplied by the acquisition probability computed from Equation 3 with R_A set equal to the discrete range.

In concept, Equation 3 gives the probability that the aircrew can convert to a launch if the unmask range or visibility is R_A. This probability is then multiplied by the probability of R_A occurring to estimate how often a launch can occur. By summing all these products together, the entire time period is covered (the discrete probabilities must add to 1.0).

The ceiling data are also entered as a cumulative probability of the ceiling being at least as high as a given altitude. The user may operate the program without ceiling being included (i.e., the assumption of a clear sky), or with a ceiling calculation. The effect of the latter is to multiply the probability of a launch by the probability of being able to fly at the chosen altitude.

III. Sample Results and Sensitivity

This section of the report presents some sample results from the algorithm. Not all of the variables were changed for the sample runs; those held constant are shown in Table 2. These weather conditions were used in the computations; for convenience in later referencing they are referred to simply as locations A, B, and C. The weather at locations A and B is similar, and would be judged good flying weather, both winter and summer. The weather at location C is worse, with much lower ceilings and poorer visibility in the winter.

The terrains chosen for the sample runs illustrate the variety to be expected, from flat, open terrain to sharply rolling terrain.

TABLE 2. Variables Held Constant in Sample Results Presented Below.

Decision time, sec	1
Roll-in time, sec	0.5
Aircraft velocity, knots	450
Minimum release range, ft	3,000
Number of *g*'s in turn	3
Roll-out time, sec	1.0

A. Target Effects

The algorithm has a large built-in target effect since the user must select the estimated acquisition probability, P_{MAX}, from Table 1; the values range from 0.25 to 1.00. This effect is illustrated in Figure 4, where P_{MAX} values of 1.00, 0.75, 0.37, and 0.25 were selected for running. The resulting probabilities of launch range from 0.75 down to 0.20; there is a direct variation in P_L when there is a variation in P_{ACQ}. This variation is a function of the algorithm user's estimate of how hard it is to find the target.

B. Terrain Effects

Figure 5 illustrates the effect of the type of terrain on the probability of launch. A fairly easy target is assumed (P_{MAX} = 0.75) and the probability of launch is about 0.50 in flat, open terrain. The launch probability is only 0.05 in shaprly rolling terrain when the aircraft is flying at low altitude, and increases to only 0.25 at an altitude of 4,000 ft.

This large terrain effect is produced by target masking by the terrain and vegetation. Although the target will be seen on 75% of the passes, it is seen too late to get off a launch on most of the passes. The major factor that interacts with the terrain effect is the aircraft altitude discussed in the next section.

C. Altitude Effects

Figure 6 shows the probability of being able to fly and launch a weapon from different altitudes under two weather conditions (December and June) in two different types of terrain. A target acquisition probability of 1.0 was assumed.

In flat, open terrain with good weather, the probability increases considerably when the aircraft goes from 500 to 1,000 feet. There is not much improvement above 1,000 feet; and, in fact, there is a slight decrement because some of the time the ceiling will be below the flight altitude.

In the same terrain with poor weather, the probability of launch decreases with altitude. Visibility causes the degradation and the probability of a clear sky at altitude gets lower the higher one gets.

The launch probability continually increases with altitude in sharply rolling terrain with good weather; masking is the cause of the degradation in this case, and the higher the aircraft flies, the better the chances of a clear line-of-sight.

In summary, increasing the planned attack altitude can either increase or decrease the percent of the time an attack can be made. Increasing the altitude overcomes masking problems, but may put the aircraft in the clouds. The weather and type of terrain must be known to determine the major effect.

Biographical Sketch

Ronald A. Erickson is head of the Human Factors Branch at the Naval Weapons Center, China Lake, California. He has a B.S. degree in physics from Idaho State, and an M.S. degree in engineering from U.C.L.A. Erickson has worked on various aspects of target acquisition for over 15 years, including detection and identification by direct vision, television, forward-looking infrared, and radar.

Carol J. Burge is a mathematician in the Human Factors Branch, Naval Weapons Center. She has a B.A. degree in mathematics and has worked in computer programming and systems analysis at the Naval Weapons Center. Burge recently completed an extensive terrain/vegetation masking measurement program and is currently working on an automatic ship classification program.

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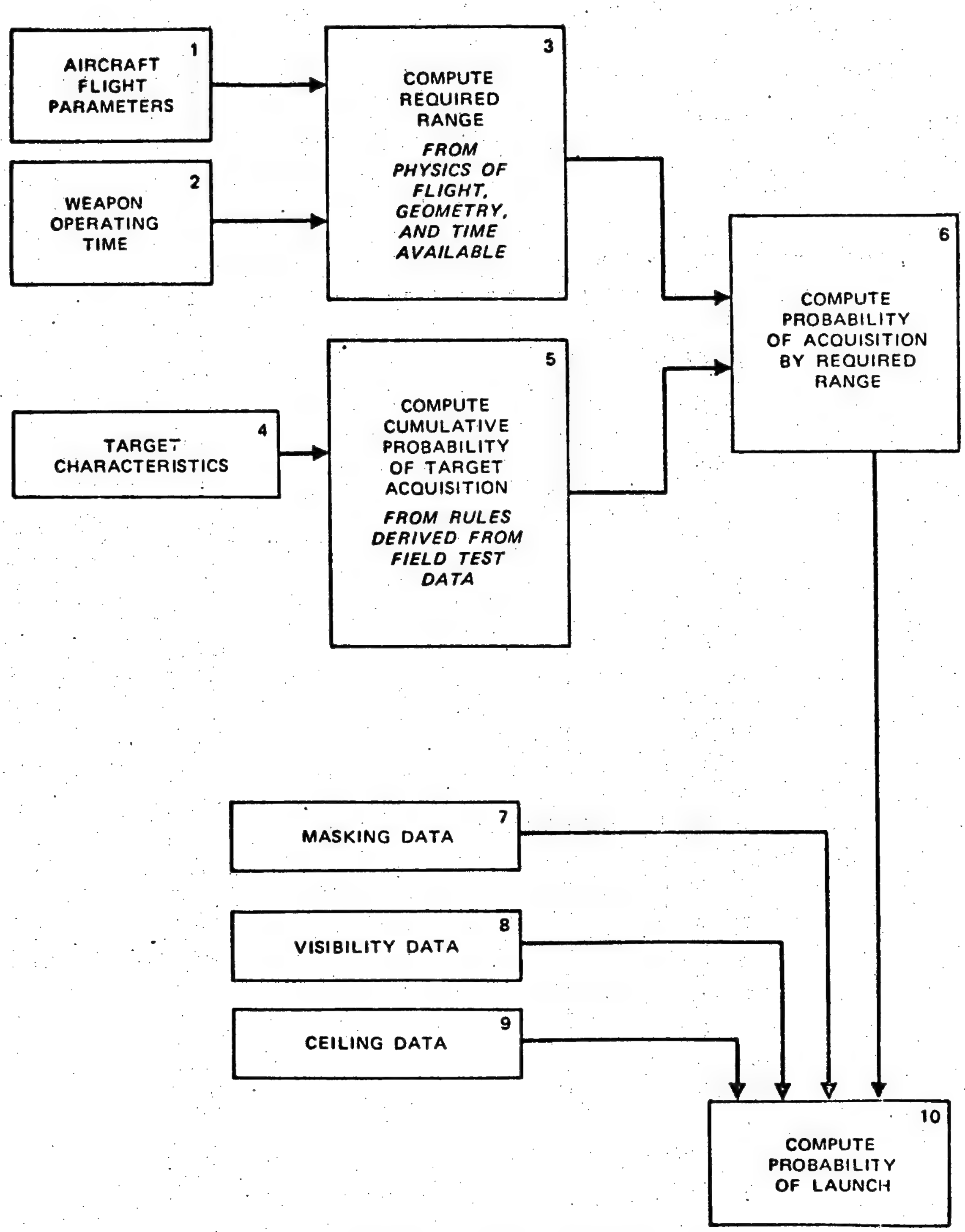

FIGURE 1. Diagram of Launch Opportunity Algorithm.

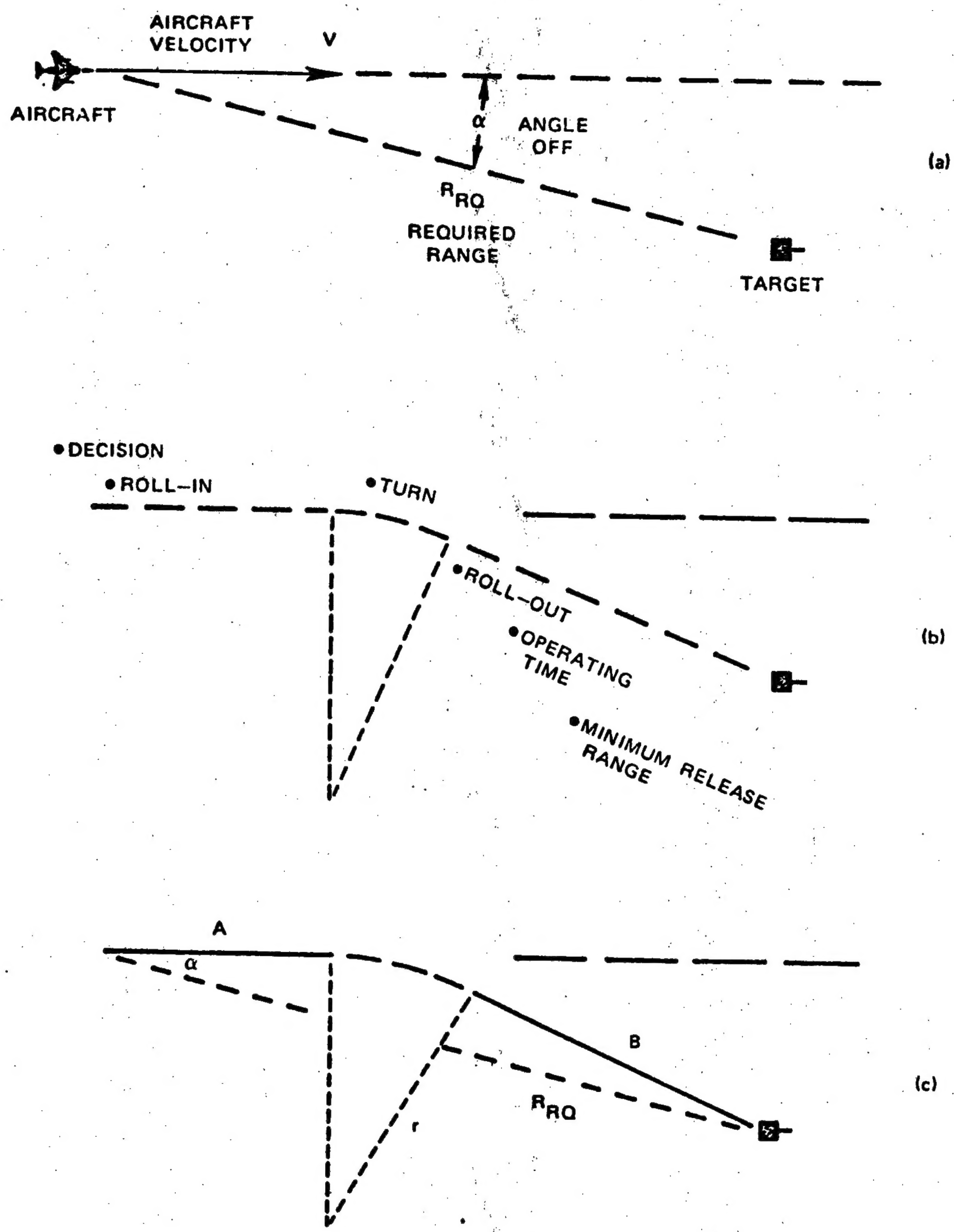

FIGURE 2. Conversion-to-Attack Geometry Used To Calculate the Required Range.

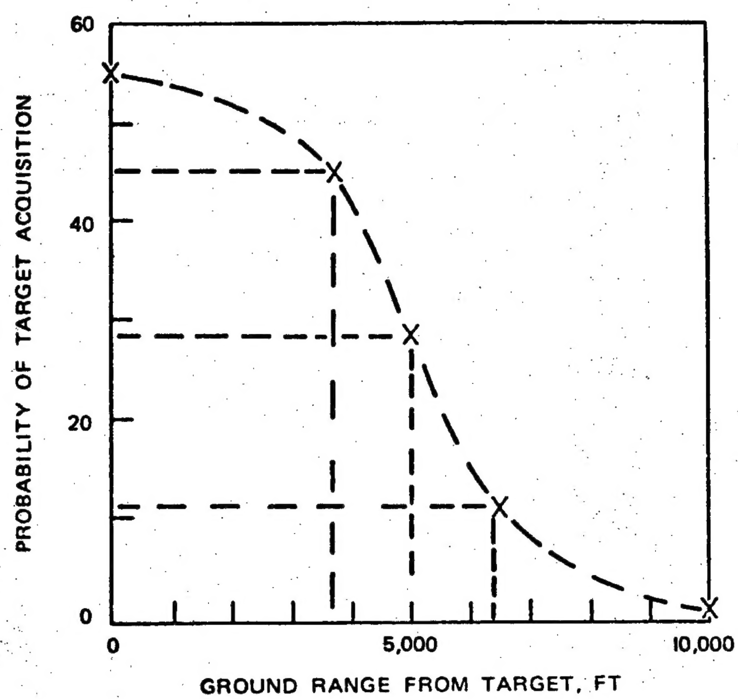

FIGURE 3. Construction of Cumulative Probability of Acquisition Curve.

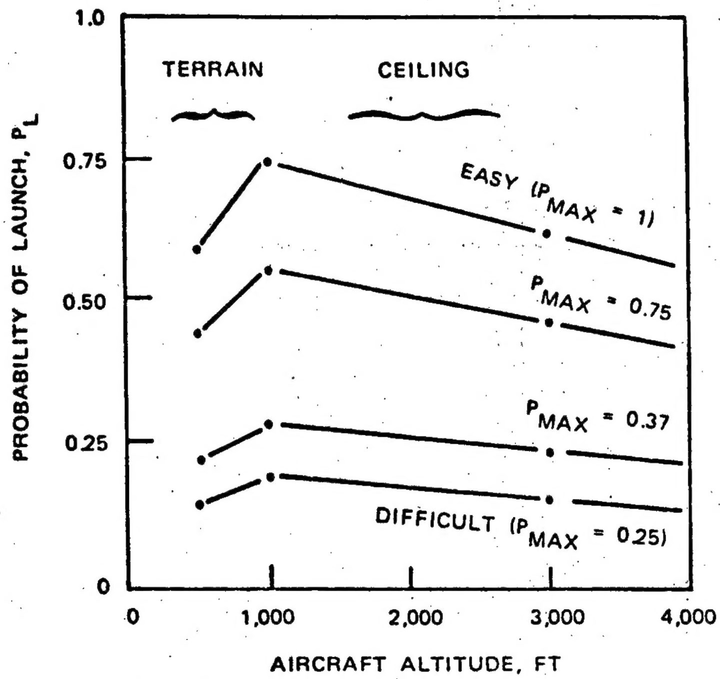

FIGURE 4. Probability of Launch as a Function of Target Acquisition Difficulty for Weather at Location B in June (Figures 10 and 11) With T_{OP} = 7 sec and Angle-Off = 15 deg. Regions of predominant terrain and ceiling effects are shown on the curves.

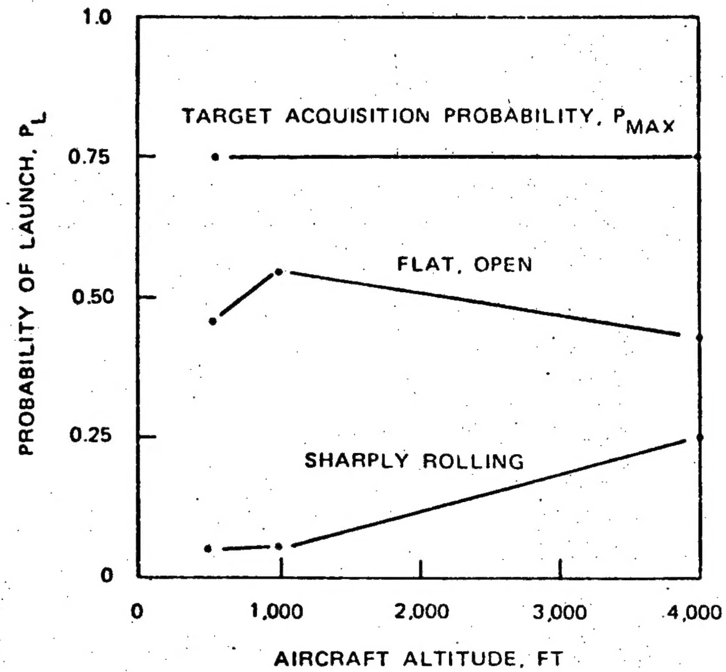

FIGURE 5. Probability of Launch as a Function of Terrain Type for Weather at Locations A or B in June With T_{OP} = 7 sec and Angle-Off = 15 deg.